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New Aggregate Alkali-Reactivity Test Methods

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Author(s): R. D. Hooton - Associate Professor, University of Toronto

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Contact Person: Alan Ip, Materials Office
(416) 235- 4641

Abstract: Components of certain concrete aggregates can react deleteriously with the alkalis in portland cement to cause expansion and cracking of concrete. Existing standard test methods for detecting deleteriously reactive aggregates are slow, often taking 12 months or longer, and are not always reliable. Often the best indicator for an aggregate is previous field performance in concrete. The purpose of this work was to evaluate several promising, non-standard, rapid test methods for reliability with respect to field performance and standard tests for a range of Ontario aggregates.

Of the 12 non-standard methods investigated, only one appeared to provide rapid yet reliable results. This was the accelelerated mortar bar test developed at the National Building Research Institute (NBRI) in South Africa.

After testing a series of 17 deleteriously reactive and innocuous aggregates with this test in the first phase of this work, 44 aggregates were then tested from every region of Ontario (all currently approved for use as concrete aggregates by MTO). However, it appears that 7 of these 44 aggregates may be reactive or potentially reactive and their acceptance should be reconsidered. In spite of passing existing specified tests, they fail this new test and some of these have shown deleterious reactions by field performance.

Based on the encouraging results, along with good results by others, the author drafted and had approved this new rapid method as a new ASTM Proposal Standard P214. Simultaneously, a similar draft method is being considered by the CSA Committee on cement-aggregate reactions. From this study, expansion limits for the mortar bars at 16 and 28 days of age are recommended.

Comments: Final Report of Research and Development Project 22337 carried out under the Ontario Joint Transportation Research Programme.

Key Words: accelerated testing, aggregate, alkali, concrete, reactivity, test methods

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R. D. Hooton
Associate Professor
University of Toronto

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The Editor, Technical Publications
Room 320, Central Building
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Table of Contents

Acknowledgements v
1/ Introduction 1
2/ Experimental 2
2.1/ Methodology 2
2.2/ Test Methods 2
2.2.1/ Expansion of Cement/Aggregate Combinations 2
2.2.2/ Evaluation of Aggregate Alone 3
2.2.3/ Standard Tests 4
2.3/ Cements 4
2.4/ Selection of Aggregates 4
2.5/ Aggregate Preparation 5
3/ Results and Discussion 5
3.1/ General 5
3.2/ Status of Testing 5
3.2.1/ ASTM C 227 Standard Mortar Bars 5
3.2.2/ Duncan Test 6
3.2.3/ Danish Salt Test 6
3.2.4/ Japanese Rapid Test 7
3.2.5/ Osmotic Cell Test 7
3.2.6/ Chinese Autoclave Test 8
3.2.7/ Danish Chemical Shrinkage Test 8
3.2.8/ CSA CAN3-A23.2-14A Concrete Prism Test 9
3.2.9/ Woolf Mason Jar Test 9
3.2.10/ Duggan Concrete Test 9
3.2.11/ S.E.M. Test 10
3.2.12/ German Sand Test 10
3.2.13/ NBRI Rapid Test 11
3.3/ Discussion of Phase 1 Results 13
3.4/ Phase 2 NBRI Rapid Mortar Bar Testing 14
3.5/ Comparison of NBRI Results to ASTM C 227 and CSA A23.2-14A Standard Tests 14
3.6/ Limitations of the NBRI Test 16
4/ Conclusions 16

Table of Contents

5/ Recommendations 17
6/ References 17
Appendicies 54

List of Tables and Figures

Tables

1/ List of tests based on cement/aggregate combinations 23
2/ List of tests based on evaluation of aggregate alone 24
3/ Previous studies of variables affecting expansion tests 25
4/ Problems reported for test methods 26
5/ Composition of test cements 27
6/ Aggregate description and field performance in concrete 28
7/ Description of aggregates used for phase II NBRI testing 29
8/ ASTM C 227 and NBRI Test expansions (%) 33
9/ Duncan, Danish Salt and Japanese Rapid Test expansions (%) 34
10/ Effect of alkali addition on Japanese Rapid Test expansions 35
11/ Concrete prism design data 36
12/ German sand test results 37
13/ Additional NBRI Test expansions 38
14/ Phase 2 NBRI Test expansions 39
15/ Influence of test variations on NBRI expansions 41
16/ Field performance and expansions in various tests for AAR 42
17/ Field performance and rankings in various tests for AAR 43

Figures

1/ MTO approved aggregate sources tested in phase 2 44
2/ Comparison of 18 months ASTM C 227 expansions to 16 day NBRI expansions 45
3a/ NBRI Test - phase I innocuous aggregated 46
3b/ NBRI Test - phase I marginal (but acceptable) aggregates 47
3c/ NBRI Test - phase I reactive aggregates 48
4/ NBRI Test - phase I reactivity zones 49
5a/ NBRI Test - phase II innocuous aggregates 50
5b/ NBRI Test - phase II marginal (but acceptable) aggregates 51
5c/ NBRI Test - phase II reactive aggregates 52
6/ NBRI Test - phase II reactivity zones 53

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The work was initiated in May 1987. Two summer students, Mr. Andrew McClellan and Mr. Louis Tay were hired to work on this project along with the principal investigator, Prof. R.D. Hooton. For the remainder of 1987 and early 1988, measurements were continued by Prof. R.D. Hooton with some data logging assistance from Mr. Tay. The work was continued in the Summer of 1988 by summer students, Mr. Andrew McClellan, Ms. Samera Fares and Mr. Craig West. From the end of the summer until the spring of 1989, Mr. Louis Tay and Mr. Brent Belcher performed some computer data analysis, and Mr. Belcher and Mr. Neil Hutchings continued taking measurements. In addition, using concrete left from the MTO's Mason jar tests, Mr. Ian McCullogh evaluated Duggan's concrete core test.

In 1989, Mr. Max Castiglia, a summer student, was hired to assist Research Engineer, Ms. Jana Konecny. Final 1990 measurements were made by Ms. Nataliya Hearn and Mr. Sean McCann. The supply of high alkali cement, Paris sand and Paris Gravel by Mr. G.S. Kellay of Ontario Hydro Research Division is gratefully acknowledged.

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1/ Introduction

Deleterious expansive reactions between the alkalies (sodium and potassium) of portland cement and certain silicious components of some aggregate have been known to occur since Stanton first identified the problem in 1940. The reaction products are usually alkali - silica gels which have a large capacity for imbibing water, causing swelling and cracking of concrete.

In Ontario, numerous concrete structures have been deleteriously affected over large areas of the province. The affected structures often exhibit unsightly pattern cracking, and generally result in increased maintenance costs. In some cases, expansion can impair the function of the structure or squeeze expansion joints.

Existing standard tests for identifying reactive aggregates are lengthy and not always reliable. Therefore, there is a need for development of rapid, yet reliable test methods for evaluating the potential for deleterious alkali-aggregate reactions when evaluating a source of concrete aggregate. Petrographic analysis alone cannot predict performance but can indicate the presence of potential problem minerals based on previous experience. Probably the most widely used and trusted test (for alkali-silica reaction) is the ASTM C 227 mortar bar test, but using this test, one must wait up to 6 or 12 months or longer in order to obtain a result. In addition, the results of this test are subject to wide variations (Hooton, 1985; Oberholster, 1986; Rogers and Hooton, 1989 and 1991) unless extra attention is paid to details of the test method. The CSA A23.2-14A concrete prism test (at 23° or 38°C) is subject to the same delays in determining acceptance. The ASTM C 289 quick chemical test yields results in only a few days but has been found by many to be either insensitive or give erroneous results (Hooton, 1985; Grattan-Bellew and Litvan, 1976; Bakker, 1983; Duncan et al, 1973; Fournier and Berube, 1990). In addition, Mielenz and Benton, (1957), indicated that it is not valid for evaluation of rock containing carbonates or magnesium silicates.

The ASTM C 586 Rock Cylinder Method, while developed to detect alkali-carbonate reactive rocks, can be used for the other types of reactive rocks but again, it is not that rapid. The ASTM C 342 Conrow test has limited applicability to a narrow range of feldspar aggregates in Kansas and Nebraska and has been found to give misleading results when applied to feldspars in other areas (Hooton, 1989).

The reference list on the original Request for Proposal listed 29 different methods and provided 50 references in which they are discussed. As well, at the beginning of this project, the author found several other test methods, bringing the total to 37 (Tables 1 and 2). Many of the older, proposed test methods were abandoned for either being poor tests, having limited applicability to a narrow range of aggregates, or offering no advantage over ASTM test methods in terms of accuracy or waiting period. However, several of the cited procedures appeared to have merit and were deemed worthy of investigation in this project.

During the course of the project, many new test methods have been published, especially in the Proceedings of the Eighth International Conference on Alkali Aggregate Reactions held in Kyoto, 1989. However, a complete update on these methods has not been provided. As well, others have been doing parallel work and have helped to confirm the applicability of the NBRI rapid test (Oberholster and Davies, 1986) which is recommended in this study.

2/ Experimental

2.1/ Methodology

The more than 30 test methods in the literature can be divided between methods based on expansion of aggregate-cement combinations (Table 1) and those based on examination, expansion, or reaction of the aggregate alone (Table 2). While many of the tests have a similar basis, they usually vary in the specimen size, the alkali concentration, the type of alkali, the curing temperature and/or the particle size of the aggregate being tested. A list of references where some of these variables have been studied is given in Table 3.

One feature in common to all rapid test methods is that they are intended to accclerate the reaction relative to the situation in real structures and often in more than one respect. A potential danger is that this could over-magnify the effect of that variable(s) and lead to rejection of aggregates with satisfactory field performance.

Therefore, in addition to a range of deleteriously reactive aggregates, a number of acceptable, non-reactive (at least deleteriously) aggregates were also tested. As well, several petrographically marginal aggregates with good field performance were included to allow identification of potential over-magnification problems with the various test methods. This was also used to show limitations of particular test methods with respect to specific rock types.

Some examples of over-magnification problems or insensitivity of standard test methods are given in Table 4.

2.2/ Test Methods

For the first part of this project, the procedures tested are listed as follows:

2.2.1/ Expansion of Cement/Aggregate Combinations

2.2.1.1/ The Danish mortar bar test (Chatterji, 1978) - Bars are stored in a saturated NaCl solution at 50°C and compared to bars stored in distilled water. Some reactive aggregates are detected in a few weeks but 20 weeks are reported to be (Thaulow, 1983). In this study some tests were monitored for as long as 170 weeks.

2.2.1.2/ NBRI Rapid Mortar Bar Test (Oberholster and Davies, 1986) - ASTM C 227 bars are stored in 1N NaOH solutions at 80°C. Expansion limits after 12 or 14 days in solution have been proposed. In this study, expansions were typically monitored for 56 days.

2.2.1.3/ The Chinese Autoclave Test (Tang et al, 1983; Tang et al, 1986) - Mortar bars are steam cured prior to being immersed in 10% KOH solution at 150°C for 6 hours. Results are obtained in 2 days. Although it sounds severe, the researchers appear to have looked at many of the variables and potential problems.

2.2.1.4/ Duncan's modified C 227 test at 64°C (Duncan et al, 1973) - A limit of 0.05% expansion at 12 weeks was proposed and results were comparable to the standard C 227 test at one year.

2.2.1.5/ The MTO modified concrete prism test - Originally used for alkali carbonate reactivity (Rogers 1986) where the alkali level in prisms were raised to 3.0% Na_2O equivalent* and an expansion limit is given at 84 days. This test also appears to be appropriate for slowly reactive alkali-silicate aggregates as well (Rogers, 1990).

2.2.1.6/ The Japanese Autoclave Test (Nishibayashi et al, 1986) - Mortar bars are subjected to steam pressures of 0.15-0.20 MPa are maintained for 5 to 6 hours with 1 to 2% NaOH added. It is reported to give results similar to C 227 at 18 months.

2.2.1.7/ The SEM Test (Mills, 1986) - The volume of gel and the shrinkage of alkali-silica gel in the vacuum of the Scanning Electron Microscope is measured (on samples taken from mortar bars stored at 60°C for 14 days) with results available within 3 weeks. Although probably not suitable as a standard procedure, it may yield information which could lead to a more practical procedure based on the same concept.

2.2.1.8/ The Woolf mason jar test (Woolf and Smith, 1948) - Concretes are cast inside glass mason jars and failure occurs if the jar breaks due to expansion of the concretes.

2.2.1.9/ The Duggan test - developed by the Canadian National Railway (Scott and Duggan, 1986; Duggan and Scott, 1989) where small concrete cores are given three dry heat cycles prior to storage in water for approximately 20 days.

2.2.2/ Evaluation of Aggregate Alone

2.2.2.1/ The Osmotic Cell Test - This test was designed by Verbeck and Gramlich in 1955 and has been more recently employed by Stark (1983). The aggregate is placed in a two chamber cell on one side of a semi-permeable membrane. On the other side of the membrane is NaOH solution. As reaction occurs, one way flow of solution through the membrane causes a volume change of the height of solutions between the two sides as measured in capillary tubes.

2.2.2.2/ The German NaOH test - This test was described by Smolczyk (1973) and Jensen et al (1982). Various size fractions of aggregate are placed in 4 or 10% NaOH at 90°C for one hour and the loss in mass on specific sized sieves is determined. It is most effective with opaline sandstone. This appears to be similar to, but not the same as a method used by Stanton (1940) but later found to be unreliable (Stanton, 1943).

2.2.2.3/ The Danish Quick Chemical Shrinkage Method (Knudson, 1986) - Sand is placed in 10 N NaOH at 50°C for 20 hours and chemical shrinkage is measured. This appears to be effective for flints and chalcedonic cherts, but temperature stability is critical in order to obtain accurate measurements.

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*$\%Na_2O$ equivalent = $\%Na_2O + 0.658 \times \%K_2O$ in the portland cement

2.2.3/ Standard Tests

It was agreed that C. Rogers at MTO would obtain the various aggregates for the program and perform the petrographic analysis and the CSA A23.2-14A at both (23°C and 38°C) standard tests on the aggregates. This was to ensure that all of the standard tests were carried out in accordance with the various standards. The MTO modified concrete prism tests, as detailed in Table 1 (Rogers, 1990) and in Section 2.2.1.5, were carried out at the MTO laboratories as well. The ASTM C 227 mortar bar tests in two different storage conditions were carried out at the University of Toronto with some additional testing performed at the MTO laboratories. Because some aggregates may be slowly reactive, these tests were monitored for longer term expansions than the typical 6 or 12 month period. Tests were extended into 1990 for ages of up to 1200 days (40 months).

2.3/ Cements

A single high-alkali (1.17% Na_2O equivalent). Type 10 portland cement was employed for the whole of the initial test program during 1987 and 1988. A laboratory standard cement blended from four Ontario cements was obtained from Ontario Hydro. It's composition is detailed in Table 5.

In 1989, for the evaluation of the larger suite aggregates by the NBRI procedure, a high alkali Type 10 cement (0.89%Na_2O equivalent) from St. Lawrence cement in Clarkson, Ontario was stockpiled by the MTO and supplied for this project. A typical composition of cement from this source is also given in Table 5.

2.4/ Selection of Aggregates

The MTO supplied most of the initial series of 12 reactive and non-reactive aggregates for the project. These were equally divided between the two categories and represented a broad spectrum of aggregate types encountered in Ontario. As stated previously, the problem with evaluating many reactive aggregates and only one or two non-reactive ones is that there is a danger of either over-magnification of apparent reactivity or that selected tests will have limited applicability to a narrow range of aggregates. It was further decided that some of the "non-reactive" aggregates be marginal, i.e. some petrographically deleterious components but with good service records: e.g., Guelph Sand, Paris Sand and Gravel which all contain small amounts of porous chert. To simplify the task, it was decided that only alkali-silica and silicate susceptible rock types be evaluated. This is not to downplay the importance of the alkali-carbonate problem, but the mechanism of reaction and appropriate test procedures for this type of problem has been dealt with elsewhere (Rogers, 1986). The ..st aggregates are described along with field performance data in Table 6.

In addition, C. Rogers supplied several extra reactive aggregates in 1988 and for the Phase 2 program in 1989, over 30 aggregates from all over the province which are currently used by the MTO in structural concrete were supplied for testing by the NBRI procedure. A description of these aggregates is given in Table 7 and their locations are marked on a map in Figure 1.

2.5 Aggregate Preparation

For the original 12 aggregates a jaw crusher and then a cone crusher were employed to produced ASTM C 227 test size fractions (Imperial sieves) of:

%	CSA SI sieves	C227 Imperial Sieves	C227 SI Sieves
10%	2.5 - 5.0 mm	(#8 - #4)	2.36 mm - 4.75 mm
25%	1.25 - 2.5 mm	(#16 - #8)	1.18 mm - 2.36 mm
25%	0.63 - 1.25 mm	(#30 - #16)	0.60 mm - 1.18 mm
25%	0.315 - 0.63 mm	(#50 - #30)	0.30 mm - 0.60 mm
15%	0.16 - 0.315 mm	(#100 - #50)	0.15 mm - 0.30 mm

These were then wet-sieved to remove dust as required by ASTM C 227. The graded and washed materials were then used for the ASTM C 227 test, the NBRI, Danish, Japanese and Chinese tests (using Imperial sieves). For the 1989 series of NBRI tests, the aggregates were first jaw crushed at the MTO laboratories then sieved (using CSA SI sieves). A disk mill was employed as required for final crushing prior to washing.

3/ Results and Discussion

3.1/ General

Draft test methods of the promising NBRI rapid test procedure were prepared for both the CSA A5 subcommittee and the ASTM C9.02.02 Chemical Reactions Subcommittee by the author (based on experience with the NBRI method in this project along with simultaneous evaluations by other Canadian researchers). The author has had this method approved as ASTM Proposal Standard P214 (1989). The author has also kept both the CSA and ASTM subcommittees informed of progress in this project and papers on some of the previously reported results were recently published in the International Conference on Alkali-Aggregate Reactions in Kyoto (Hooton and Rogers, 1989) and in Toronto (Hooton and Rogers, 1990).

Complete and detailed test results are not included in this report for all test methods due to the volume of data. A separate appendix binder is being provided to C. Rogers of MTO.

3.2/ Status of Testing

3.2.1/ ASTM C 227 Standard Mortar Bars

This is the most widely accepted standard test in the world for evaluating aggregates for alkali-silica reactivity. Test limits are specified at 3, 6 and 12 months (CSA A23.1-M90 Appendix B). Most of these standard tests were initiated in 1987 but the remainder were started in 1988 and all were continued into 1990 to ages of up to 1200 days (40 months). For each aggregate, six 25 x 25 x 250 mm gauge length bars were stored inside the MTO-supplied, wicked, 18-bars stainless steel boxes over water at 38°C. Three bars in each set were further heat-sealed into individual polyethylene tubes with about 10 ml of water. Average expansions after 6, 12, 18 and 24 months storage are given in Table 8. For deleteriously expansive aggregates, the bagged bars expanded much more than those in the wicked containers due to lower levels of alkali-leaching [the problem of alkali-leaching has been studied separately (Rogers and

Hooton, 1989 and 1991)]. For comparison, for a limited set of aggregates, four 25 x 25 x 125 mm gauge length bars were cast and placed in plexiglass, 4-bar, unwicked containers over water at 38°C. These containers were similar in design to those in use by Ontario Hydro since the early 1950's. The expansions in these containers were approximately 20% higher after 6 months than the bagged bars as shown in the following table.

COMPARISON OF ASTM C 227 EXPANSIONS AT 6 MONTHS (%)

	ONT. HYDRO	MTO	
AGGREGATE	UNWICKED	SEALED	WICKED
SPRATT*	.200	.166	.046
SUDBURY*	.047	.036	.022
PARIS GRAVEL**	.021	.025	.021

* Deleteriously Reactive, ** Non-reactive

It should be noted that even when properly stored to minimize alkali-leaching effects, of the 12 aggregates, only the Spratt aggregate exceeded the ASTM, CSA and OPSS expansion limit of 0.10% at 6 months, or even the more stringent U.S. Bureau of Reclamation, U.S. Army Corp, of Engineering and Ontario Hydro limit of 0.10% at 12 months. Yet from Table 6, six of the 12 test aggregates are known to be deleteriously reactive in concrete. From the data in Table 8, it would appear that for ASTM C227 tests, a limit of approximately 0.05% at 12 months would be more appropriate for discriminating all of the reactive aggregates in this study.

3.2.2/ Duncan Test

In this accelerated test, ASTM C 227 bars were heat-sealed in bags and stored horizontally over water in sealed plastic containers at 64°C. The expansions after 12, 16 and 26 weeks (6 months) are given in Table 9. There was insufficient Lower Notch Aggregate to make bars for this test, but reactive pyrex glass (prepared according to ASTM C 441) was included.

Based on Duncan's suggested expansion limit of 0.05% at 6 months (Duncan et al, 1973), only the Pyrex Spratt and Sudbury aggregates would be considered reactive. As well, all of the expansions at 6 months (26 weeks) were higher than the ASTM C 227 bars at 6 months so while the test does accelerate the rate of expansion, but the acceleration factor is small. It was encouraging that the reactive Sudbury aggregate was detected with this test procedure since it passes the ASTM C 227 test.

Expansions were monitored for over 2 years but in all cases, the expansions were essentially completed after 9 months (270 days).

3.2.3/ Danish Salt Test

This test was modified from that proposed by Chatterji, (1979) by adopting ASTM C 227 mortar bar proportions and specimens instead of RILEM 40 x 40 x 160 mm mortar bars. Six bars were cast, with

three stored in saturated NaCl solution at 50°C and three in distilled water at 50°C (the bars were cooled to 23°C prior to taking measurements). Because of concern with corrosion of normal stainless steel studs in this environment, they were manufactured from Grade 316 stainless threaded rod. Based on 8, 20 and 52 week expansions given in Table 9, none of the aggregates exceeded the suggested limit of 0.10% (Thaulow and Olafsson, 1983). In fact, when the 20 week expansions of the bars stored in water were subtracted from the expansions in saturated NaCl, all of the "corrected" expansion were negligible.

Based on the poor performance of this test and the apparent lack of acceleration, it was decided not to waste resources by casting bars for the remaining 3 aggregates (Ottawa sand, Grant's pit and Natural sand), Existing bars continued to be measured periodically but even after 52 weeks, deleterious expansions had not occurred. However, larger expansions (0.17 to 0.33%) did occur after 1.5 to 2 years for the Fleming, Neyes, Paris gravel, Lower Notch and Spratt aggregates.

3.2.4/ Japanese Rapid Test

This test method (Nishibayashi et al, 1986), which uses low pressure steam to accelerate expansion of mortar bars with 3.0% added alkali, was modified by using ASTM C 227 aggregate gradations, mix proportions and bars.

Initial results were discouraging, and even after repeating the 4 hour steam cycle, deleterious expansions were not found as shown in the following:

Aggregate	Average Expansion (%)	
	One 4 Hour Steaming	Two 4 Hour Steamings
Fleming	0.035	0.034
Guelph	0.034	0.046
Sudbury	0.042	0.044
Lower Notch	0.049	0.061
Spratt	0.043	0.095

However, 25 x 25 x 125 mm gauge length mortar bars were used in lieu of the Japanese bars. To see if this had altered the optimum conditions for expansion, a second set of tests was carried out. In this second test, both Spratt and Nelson aggregates were mixed with 3.0, 3.5 and 4.0% added Na_2O (by mass of cement) using the same size bars. These results are shown in Table 10. It appears that 4% Na_2O results in much higher expansions for the reactive Spratt aggregate while not affecting the non-reactive Nelson stone.
Therefore, further tests on the whole suite of aggregates was performed with 4.0% added NaOH. The bars, made with added NaOH solution, were stripped, at 24 hours and subjected to saturated steam in a pressure cooker at 125°C (0.15 MPa steam pressure) for 4 hours. Unfortunately as shown in Table 9, only the Spratt aggregate expanded more than 0.10%. Therefore, this test was abandoned.

3.2.5/ Osmotic Cell Test

After several discussions with D. Stark of the Construction Technology Laboratories (CTL) in Skokie, Illinois, three larger than normal 4 inch (102 mm) diameter Osmotic cells were manufactured. These

larger cells allow testing of more representative samples of aggregate than that originally proposed (Verbeck et al, 1955).
Six of the aggregates were tested but with little success. For example, the reactive Spratt aggregate did not result in Osmotic flows larger than those with the non-reactive Nelson stone. Therefore, this test was abandoned and results are not reported.

Subsequent discussions with D. Stark's technician in 1987 indicated that problems had been experienced at Construction Technology Laboratories with sealing between the two parts of the cell around the cement paste membrane. Therefore, there may have been leaks in this study as well.

3.2.6/ Chinese Autoclave Test

This test (Tang et al, 1983) involves first steam curing the mortar bars to cure them, then autoclaving them in 10% KOH at 150° for 6h.

As set of tests was undertaken using Spratt, Sudbury, Nelson and Lower Notch aggregates. Stainless steel containers with bars and the KOH solutions were placed inside a standard cement testing autoclave (ASTM C 151) which had been adjusted to 150°C. The results did not appear very promising since the expansions of both the three reactive aggregates and the non-reactive Nelson stone were similarly low. However, the procedure had been altered to use 25 x 25 x 125 mm gauge length mortar bars and ASTM aggregate/cement ratios of 2.25/1.0 and these changes probably had a major influence on the results as shown in the following table.

Aggregate	Expansion (%)	
	Test 1	Test 2
Nelson	0.032	-
Sudbury	0.032	0.038
Lower Notch	0.028	-
Spratt	0.048	0.046

3.2.7/ Danish Chemical Shrinkage Test

Aggregates were immersed in NaOH solutions inside sealed test tubes connected to calibrated capillary tubes all inside a controlled temperature bath. The volume of fluid in the capillary is supposed to reduce as alkali-reaction takes place due to a reduction in volume of the constituents (Knudson, 1986). Unfortunately, initial tests were not successful and this method was also abandoned. (Later discussion with T. Knudson in Kyoto showed that there were critical procedural details which were not clearly outlined in this paper).

3.2.8/ CSA CAN3-A23.2-14A Concrete Prism Tests

Tests were initiated at the MTO laboratories in April 1988, two concrete mixes were made with each aggregate as follows:

1. 400-415 kg/m^3 cement content with effective w/c fixed at 0.41 and with the Na_2O equivalent of the cement boosted to 1.25% by addition of NaOH to the mixing water.
2. 300-315 kg/m^3 cement with variable w/c and the Na_2O equivalent of the cement boosted to 3.0% by addition of NaOH to the mixtures.

Coarse test aggregates were mixed with MTO Standard Guelph sand (Table 11). Fine test aggregates were mixed with MTO Standard Nelson crushed stone (Table 11). The Ontario Hydro Cement listed in Table 11 is the same as that given in Table 5. Nine prisms were cast from each mix and divided up for storage in 3 environments as follows:

a) moist room at 23°C,
b) immersed in 5% NaCl solution at 23°C,
c) in a sealed box with filter paper wicks, over water at 38°C.

The results of these expansion tests are detailed in Appendix A along with data on strength and observations. These modified, standard tests provide a good standard to better judge the rapid test methods. For comparison, the 6 and 12 month concrete prism expansions are later compared with ASTM C 227 and NBRI mortar bar expansions in Table 16.

3.2.9/ Woolf Mason Jar Test

Concretes, from the same mixes used to cast the concrete prisms, were cast by MTO staff into both plain glass Mason jars (Woolf and Smith, 1948) and Mason jars with their inside surfaces coated with a vinyl resin base paint (to prevent reaction of the cement alkalies with the glass). After 24h at 100% rh, 25 ml of water was placed in each jar, then each was sealed, and stored at 38°C. Jars were visually inspected daily for two months and then monthly to see if the jar had cracked due to alkali-aggregate reactivity. Results were reported in an internal MTO memorandum (Boothe, 1989). The results of the uncoated jars were unsatisfactory (due to reaction with the glass which cracked the jars) while many of the coated jars filled with reactive concretes had not cracked after 6 months. Therefore, it was thought that although the results with the coated jars were interesting, the test offered no time advantage over existing test methods. No results are reported here.

3.2.10/ Duggan Concrete Test

This controversial test was developed by Ross Duggan at CN's laboratories in Montreal (Scott and Duggan, 1986; Duggan and Scott, 1989). In the original version of this test (which was performed in this study), small concrete cores are obtained and subjected to three wetting and 80°C drying cycles, then after taking the initial length of dried cores, their expansions are measured when subsequently stored in water a further 20 or 30 days. Expansions of more than 0.10% after this test period were considered deleterious. (Later, the test was modified extensively to account for expansion on re-wetting of the cores, and a new limit of 0.05% was suggested). The mechanisms of expansion in this test have recently been found to be largely unrelated to alkali reactivity (Jones, Grabowski, Quinn and Gillott, 1990), hence the controversy. For this test, the concrete from the discarded MTO Mason jars and some companion concrete cylinders

from the concrete prims tests were obtained. However, attempts to drill 18 and 22 mm cores failed (the small diameter cores were easily broken) and it was decided to cut either 22 mm or 25 mm square cross-section prisms, each 50 mm long. Five or six replicate prisms were cut from each concrete.

While no results are presented, if 0.10% expansion after 20 days soaking in water (post-cycling) is used as a limit (there was also a recommendation to measure expansion at 30 days), this method indicates that Paris sand, Paris gravel, Nelson stone and Guelph sand are innocuous. Those exceeding 0.10% expansion include Spratt, Sudbury, Fleming, Grant, Natural sand and Neyes sand (all for the 415 k/m^3, 1.25% Na_2O eq. mixes). All of these aggregates appear to have been ranked correctly with the possible exception of the Fleming stone which, while thought to possibly be reactive, has not been found to be reactive by any of the other standard or accelerated test methods.

As well, if the moist specimens were pre-dried in an oven at 110°C for 24h before initiating the Duggan treatment cycle, expansions were found in every case to be increased significantly. This would likely be due to cracking of the concrete during drying and subsequent opening of these cracks on later re-wetting. For the 10 sets of concretes pre-dried, the average increase in expansion was 23.1% at 20 days and 28.1% at 30 days.

While these initial results are interesting, this test takes about three times the length of time and involves considerably more work then does the NBRI test. As well, Duggan's own tests have found that in combination with certain cements, the known innocuous Nelson stone and Ottawa sand have been found to expand more than 0.10%. Therefore, other mechanisms besides alkali-reactivity such as delayed ettringite formation may induce expansion failure (Jones, Grabowski, Quinn and Gillott, 1990; Attiogbe, Wells and Rizkalla, 1990), and it is not recommended that further tests be conducted. As well, because part of the expansion (in the original test) was due to water absorption, the numbers obtained are not really valid. The mechanisms of expansion in the test method continue to be studied by Prof. J. Gillott at the University of Calgary and by Prof. S. Rizkalla at the University of Manitoba. Preliminary results indicate that secondary ettringite formation and not alkali aggregate reactivity may be responsible. If this is the major mechanism, then this test may be an artifact of the heat cycling which upsets the stability of the sulphate components.

3.2.11/ S.E.M. Test

Prof. R.H. Mills examined 6 sets of mortar bars made with only the 160 to 310 µm size fraction of the aggregates and moist cured at 70°C for 14, 28 and 56 days. By examination of the cured mortar bars in the scanning electron microscope (SEM), some qualitative success in ranking the aggregates was achieved by measuring crack widths (due to dehydration of the alkali silica gel). Because of the need for sophisticated equipment and the qualitative nature of the results, this work was discontinued after initial trials.

3.2.12/ German Sand Test

In this method (Jensen et al, 1982) which was developed for sands, the aggregate is divided into 1 to 2 and 2 to 4 mm size fractions (1.15 to 2.3 mm and 2.3 to 4.75 mm standard CSA sieves were used in this study). For the 1 to 2 mm size fraction, a 100 g sample is digested in 4% NaOH solution at 90°C for 60 minutes, while for the 2 to 4 mm fraction, a 200 g sample is similarly digested in 10% NaOH solution.

Afterwards, the samples are wet-sieved over 0.5 or 1.0 mm sieves (0.63 or 1.15 min in this study). The washed sands are then dried and mass losses are measured. The loss in mass is considered the alkali-soluble fraction and higher losses are considered to be indicative of reactivity.

The alkali soluble fractions for aggregates washed to each of the two sizes are indicated in Table 12. It can be observed that the alkali soluble fractions are all low and there is no apparent relationship with reactivity. This might be expected since major reductions in particle size would only occur in aggregates such as cemented sandstones where the cementing material between the grains is reactive and breaks down during the test.

3.2.13/ NBRI Rapid Test

3.2.13.1/ Results - In this test, ASTM C 227 bars are heated in water up to 80°C for one day after stripping the molds then the expansions in subsequent storage in 1N NaOH solution at 80°C are measured at 14 or 16 days of age (Oberholster and Davies, 1986). The average expansions after 14, 16, 28 and 56 days of age are given in Table 8. In later work, Davies and Oberholster (1987) suggested limits after 14 days of age of:

14 Day	Interpretation
0 - 0.10%	innocuous
0.10 -0.25%	slowly or mildly reactive
>0.25%	rapidly reactive

For this study, it was decided to use 16 days of age (14 days in NaOH solution) as the standard test period. This was due to some initial confusion about the method which resulted in most CSA committee members studying this test method using 14 days in NaOH solution for the test. The 16 day expansions are compared to 18 month ASTM C 227 expansions in Figure 2. It may be noted in Figure 2 that all aggregates with poor field performance had the highest NBRI expansions.

Comparing the 16 day expansions (Table 8) to field performance (Table 6), three of the six reactive aggregates expanded more that 0.25% while the other three expanded more than 0.16%. Of the other 6 aggregates with excellent or unknown field performance, four expanded less than 0.10% while two expanded less than 0.18% (Paris sand and Paris gravel). These two Paris aggregates have a long service record without problem, in concrete and have never shown deleterious expansion in ASTM C 227, but they do contain small amounts of alkali reactive porous chert. The porous chert tends to be more of a concern with respect to popouts from freezing are thawing.

Therefore, based on this first set of results, this test method appeared very promising, but more appropriate expansion limits for the initial suite of aggregates after 16 days (14 days in NaOH solution) might be:

16 day	Interpretation
<0.15%	innocuous
0.15 → 0.20%	questionable (further tests required)
>0.20%	reactive

3.2.13.2/ Consideration of Alternate Test Ages for the NBRI Test - From Table 8, it can be noted that for the 16 day expansion range of 0.15 to 0.20%, the distinction between petrographically marginal but acceptable aggregates (Guelph sand, Paris sand and Paris gravel) and reactive aggregates (Neyes, Grant, Natural) is not well defined. However, since many of the bars continued to expand afterwards, they were all monitored for at least 56 days as shown in Table 8 and Figures 3a, 3b and 3c. This also allowed observation of any late or unexpected expansions of marginal or unreactive aggregates. At 56 days, the six reactive aggregates (Sudbury, Spratts, Natural, Neyes, Lower Notch, Grant's Pit) had all expanded from 0.513 to 0.956%, the marginal aggregates (Guelph sand, Paris sand, Paris stone) had all expanded from 0.297 to 0.399% and the non-reactive aggregates (Nelson stone, Fleming, and Ottawa sand) had expanded from 0.039 to 0.205%. Therefore, the later age expansions appear to have separated the slowly reactive aggregates from the good performance ones. If an arbitrary limit of 0.48% at 56 days is adopted, then both Paris sand and Paris gravel would be correctly deemed innocuous while all of the deleteriously reactive ones would fail. Likewise, at 28 days, a limit of 0.33% would also differentiate these aggregates. Because of time considerations, a 28 day expansion limit would be preferable. Figure 4 shows the range of expansions and these proposed test limits for the Phase 1 NBRI tests.

From the Phase 2 NBRI test program, which will be discussed in Section 3.4, all of the additional aggregates with 16 day expansions greater than 0.25% would also fail either or both of these suggested 28 and 56 day limits. Of all the aggregates in the 0.15 to 0.20% range at 16 days, only one (89-40065) would fail either of these suggested 28 and 56 day limits.

Therefore, extending the test time beyond 16 days (14 days in NaOH) may be useful for distinguishing petrographically marginal aggregates from mildly reactive ones, but more data would be useful to confirm these findings.

3.2.13.3/ Variations in Test Procedure - It was decided to use a limited series of five aggregates for evaluation of the influence of test variations on expansions. The NBRI test, as originally proposed, followed ASTM C 227 in that mortars were mixed to a constant workability (with variable w/c) and all crushed aggregate fractions were washed to remove dust which might react pozzolanically to reduce expansion. The constant workability requirement can waste precious materials if flow limits are exceeded. The aggregate washing is tedious and was thought not to be required since the bars are stored in NaOH solution and the reactions should not be alkali-limited.

Therefore, one set of tests was conducted using w/c = 0.5 and one with constant flow but using unwashed aggregates. The results are shown in Table 13. It can be observed that in some cases, higher expansions were obtained when a fixed w/c was used. The lack of washing of the aggregates did not reduce the expansions significantly. Therefore, in the present CSA draft method (Appendix B) and in ASTM P214 (1989), a fixed w/c (0.44 for natural sands and 0.50 for crushed rock) has been adopted, but the aggregates are still being washed.

3.3/ Discussion of Phase 1 Results

Of the eleven accelerated methods described, only the NBRI and the original version of the Duggan test were largely successful in differentiating innocuous from reactive aggregates. For the reasons described previously, the Duggan test is not being recommended for further study in this program.

As stated previously, based on the positive results obtained with the NBRI method, along with positive results obtained simultaneously by other Canadian researchers, a draft standard method was prepared for the CSA A5 Subcommittee on Alkali-Aggregate Reactions in conjunction with Subcommittee Chairman Mr. C. Rogers (Appendix B). As well, as stated previously, the author has had this method accepted by ASTM as Proposal Standard P 214 (1989).

In 1989, the author also coordinated a CSA A5 Subcommittee sponsored interlaboratory study of the NBRI test method to study the effects of cement variations and to establish precision data. Three aggregates (Nelson, Paris sand and Spratt) and 3 cements (high alkali, low alkali, variable alkali) were used for a total of 9 tests. Bars were cast at constant w/c (0.50 for crushed aggregates, 0.44 for natural sands) rather than constant flow. When outliers were removed, the average expansions ($\bar{X}_N$, where N = number of labs) at 16 days and coefficients of variation (CV) are summarized in the following table (Hooton, 1990a):

	High alkali cement $Na_2Oeq.$ = 0.92%		Low alkali cement $Na_2Oeq.$ = 0.40%		Variable alkali cement $Na_2Oeq.$ = 0.34 to 0.98%	
Spratt	$(\bar{X}_6)$	0.422%	$(\bar{X}_6)$	0.390%	$(\bar{X}_6)$	0.457%
	CV	12.0%	CV	9.3%	CV	6.9%
Paris Sand	$\bar{X}_6$	0.181%	$(\bar{X}_6)$	0.142%	$(\bar{X}_5)$	0.188%
	CV	11.4%	CV	9.6%	CV	10.5%
Nelson	$\bar{X}_6$	0.014%	$(\bar{X}_6)$	0.016%	$(\bar{X}_5)$	0.013%
	CV	53.1%	CV	46.0%	CV	63.0%

The results were very encouraging with alkali content not being a major concern and good reproducibility of expansions (CV is not a valid indicator for non-expansive aggregates such as Nelson).

3.4/ Phase 2 NBRI Rapid Mortar Bar Testing

It was recommended that the NBRI test method be further evaluated using a wider range of aggregates with known field performance. In late 1988, Mr. C. Rogers supplied samples of six additional reactive aggregates (Maple Ridge, Ont., McNulty, N.B., Beauceville P.Q., Hudson N.Y., Springhill, N.B., and Adams, Mine, Ont.) for which concrete prism tests had been initiated by MTO. The results of NBRI test expansions on these aggregates are given in Table 14.

In 1989, Mr. C. Rogers also supplied 41 samples of aggregate from every region of the province for test. The locations of the sources were given on the map in Figure 1 and detailed identification and information was given in Table 7. All of these aggregate sources have been used in highway structures with satisfactory performance in most cases. Mortar bars with 250 mm gage lengths were cast at a constant flow of 105 to 120 (w/c = 0.44 to 0.53 for natural sands and w/c = 0.51 to 0.58 for washed stone). NBRI expansions at ages of 16, 28 and 56 days (in NaOH) are given in Table 15 and the range of expansions is shown in Figures 5a, 5b and 5c for aggregates ranked as innocuous, marginal and reactive respectively. As well, Figure 6 shows the range of expansions in relation to the proposed expansion limits for the Phase 2 NBRI tests.

It may be observed that of the 44 aggregates tested, 24 exhibited 16 day expansions of less than 0.10%, 9 ranged from 0.10% to 0.15%, 2 ranged from 0.15% to 0.20%, and 9 exceeded 0.20% (of which 4 exceeded 0.25%). Using 0.15% as a non-reactive limit, 33 out of the 44 aggregates would be classed as non-reactive. All four of the > 0.25% expansion group were fine aggregates (89-40068, 89-40072, 89-40091 and 89-40095; map locations 8, 12, 26 and 29) which contained chert (locations #8, #12) or greywacke (locations #26, #29) as potentially reactive minerals. Given the expansive nature of these few aggregates in this test, it would prudent to reconsider their suitability for use in concrete. C. Rogers later indicated that cracked concrete structures have been found where at least one of these aggregates (89-40095) has been used, but it passed ASTM C227 tests and there had been no basis for its rejection. Therefore, adoption of the NBRI test in MTO specifications could be used to eliminate these sources of potentially reactive aggregates or limit their use to concretes with low-alkali cement or other corrective measures.

3.5/ Comparison of NBRI Results to ASTM C 227 and CSA A23.2-14A Standard Tests

In Tables 16 and 17, the expansions of the NBRI accelerated mortar bar test are compared to those of ASTM C 227 mortar bars and to those of accelerated concrete prisms (CSA A23.2-14A). Numerical expansions are provided on Table 16. In Table 17, based on limits discussed in the following, test results are ranked as simply passing or failing. This allowed a quick check of consistency in test results for a given aggregate.

The 12 month expansion limit for the accelerated concrete prism test is 0.04% for concretes containing 1.25% Na_2Oeq. However, MTO experience has been that some slowly reactive aggregates, especially the greywackes and argillites, will not deleteriously expand unless the alkali content is artificially raised to 3.0% (Rogers, 1990).

The ASTM C 227 mortar bar limit is 0.10% at 6 months (as listed in the ASTM C33, Appendix XI and in CSA CAN3-A23.1, Appendix B), but major agencies building hydraulic structures (Ontario Hydro, US

Bureau of Reclamation, US Army Corps of Engineers) use 0.10% at 12 months. However, from the author's experience, it is thought that any bars with expansion greater than 0.05% at 12 months will eventually reach 0.10% (in 1.5 to 3 years) and are likely slowly reactive.

As already discussed, with the NBRI accelerated mortar bar test and for the range of Ontario (mostly) aggregates tested, expansions of less than 0.15% after 16 days of age (14 days in solution) are thought to be innocuous, while those expanding more than 0.20% are considered deleterious. In fact, based on the data in Table 8, a limit of 0.175% might be appropriate to distinguish petrographically marginal aggregates from slowly reactive aggregates. However, this might be too unconservative in some cases and adoption of 28 or 56 day expansion limits are likely more helpful for distinguishing these two groups.

If the data in Tables 16 and 17 are examined, it can be observed that while the test results for six aggregates are consistent and in agreement with field performance, eleven are not. Both Nelson and Guelph sand are innocuous in all tests while Spratt, Beauceville, Springhill, and Adams Mine are consistent deleterious.

With the exception of Springhill, ASTM C227 is not able to show the aggregates containing greywacke and argillite as being reactive (Sudbury, Grant, Maple Ridge, Lower Notch).

In all cases, the NBRI test was able to differentiate the aggregates exhibiting deleterious field performance at 28 or 56 days. However, at 16 days, the two aggregates from Paris, containing leached chert, also expanded excessively. If the 0.33% limit at 28 days is adopted, then these Paris aggregates would differentiate from the reactive ones. The field performance of Neyes is poorly known but it is suspected of being reactive. The concrete prism test is only able to distinguish the slowly reactive greywacke and argillite aggregates if 3.0% alkalis are added and bars are stored at 38°C (Sudbury, Grant, Maple Ridge, McNutty). Lower Notch was also detectable @ 1.25% alkali at 38°C.

The only problem with the concrete prisms made with an elevated 3% alkali content is the danger that the elevated alkali level could induce some aggregates to cause expansion where they would not in the field. While not made at 3% alkali in this series of tests, previous tests by Ontario Hydro on Paris sand and gravel (containing some porous chert but with satisfactory field performance in concrete) at approximately 3% alkali exhibited unacceptable expansions similar to the Fleming aggregate in this study (Hooton, 1990b) Therefore, while the 3% alkali may be needed to detect slowly reactive argillites and greywackes, it may not be appropriate for all aggregates.

In summary, the following recommendations are made with respect to suggested expansion limits for detecting alkali-silica or slow/late expanding alkali-silicate/silica reactive aggregates:

1. ASTM C 227 mortar bars: 0.05% at 12 months (using either bagged bars or a non-wicked container).

2. CSA CAN 3-A23.2-14A concrete prisms: 0.04% at 12 months at 38°C using concrete mixtures with 400-415kg/m^3 of cement and alkali content of 1.25% Na_2O equivalent (by mass of cement) except for aggregates containing significant quantities of argillites and greywackes where 3.0% Na_2O equivalent is to be used.

3. NBRI accelerated mortar bar test: 0.15% at 16 days of age (14 days in NaOH). Possible later age expansion limits might be 0.33% at 28 days of age (26 days in NaOH) or 0.48% at 56 days of age (54 days in NaOH). These limits are only based on the data presented in Table 8 and should be confirmed with a more extensive set of data.

3.6/ Limitations of the NBRI Test

Recent unpublished work by Stark (1991) and others has indicated that deleteriously reactive aggregates containing strained quartz such as gneiss and quartzite (the gneisses in question are found along the eastern seaboard of the US) do not expand significantly using the NBRI test. However, these reactive aggregates are not detectable by standard tests such as ASTM C227 either. It is possible that these aggregates are sensitive to particle size and will not expand when crushed to sand size fractions. The author will be investigating this possibility in the near future. In the interim, the NBRI test is not recommended for evaluation of aggregates suspected of containing deleterious strained quartz.

4/ Conclusions

Several rapid test methods were conducted on a suite of aggregates and compared to the results of standard test methods.

Conclusions from this are:

1) Many rapid test methods were found not to be suitable either due to differences of aggregate types in the study or sensitivity to modifications such as casting ASTM style mortar bars.

2) a) The only rapid test method which gave promising results was the NBRI accelerated mortar bar test. It is a very aggressive accelerated test but it appears to be suitable for rapid deletion of alkali-silica and late expanding alkali-silicate/silica reactive aggregates. b) Its shortcoming may be with differentiating petrographically marginal but acceptable (in terms of field performance) aggregates from mildly reactive ones. (Also, from work done elsewhere, it is not likely suitable for evaluation of aggregates containing strained quartz). c) However, if an expansion limit of 0.15% at 16 days of age is adopted, most of the questionable results disappear, and if this test is continued, a limit of 0.33% at 28 days and possibly 0.48% at 56 days also help differentiate the remainder of the marginal from reactive aggregates.

3) The standard ASTM C 227 mortar bar test is sensitive to both variations in relative humidity of storage containers and alkali leaching and must be conducted carefully. Also, the current CSA and ASTM expansion limits are not conservative and should be tightened up to perhaps 0.05% at 12 months for critical situations or for aggregates containing minerals susceptible to slow/late expanding alkali-silicate/silica reactivity as defined in Appendix B of CAN/CSA-A23.1-M90.

4) The 38°C CAN/CSA-A23.2-14A accelerated concrete prism test with 1.25% alkali can detect only rapidly expansive alkali-silica reactive aggregates. For slow/late expanding alkali silicate/silica aggregates, increasing the alkali level to 3.0% is effective (still using the current CSA 0.04% expansion limit) in most cases. However, with a few aggregates, the 3% alkali may cause unrealistically deleterious expansions.

5/ Recommendations

1. The standard CSA and ASTM test methods for detecting deleteriously alkali-reactive aggregates are currently inadequate for all the aggregates used in Ontario. This is especially true for the slow/late expanding alkali-silicate/silica reactive aggregates. It is recommended the NBRI rapid mortar bar expansion test (the CSA proposed name for this test is the Mortar Bar Accelerated Test (MBAT)) be adopted as it offers the advantages of being relatively rapid, reproducible, more effective in detecting potentially deleterious aggregates. It is now being investigated by many other agencies (e.g. CSA, ASTM, National Research Council, Ontario Hydro, Ministry of Transport Quebec, Portland Cement Association, and several US state highway authorities eg Virginia, Maryland, Delaware, S. Dakota). The author has produced this method as the ASTM P214 Proposal Standard (appearing in the 1990 Book of Standards, Vol. 04.02) and has collaborated to produce a similar draft method for CSA (attached as Appendix B).

   Based on final results (the draft standard in Appendix B was produced well before completion), the following 16 day of age expansion limits are recommended.

   ≤0.15%: Acceptable for use when combined with satisfactory appraisal by petrographic analysis

   ≤0.20%: More information (ie field performance data) and testing are needed before acceptance, unless subsequent expansion at 28 days of age is ≤0.33% (for chert containing aggregates).

   >0.20% There is a high probability that this aggregate is deleteriously reactive and should not be used without a record of satisfactory field performance in high alkali cement concrete and/or extensive expansion testing in concrete at high cement alkali contents.

2. It is recommended that tighter limits for the ASTM C227 expansion test be considered.

3. It is recommended that the CAN/CSA-A23.2-14A concrete prism test be modified for evaluating aggregates suspected of containing slow/late expanding alkali silicate/silica reactive components for these cases, it is suggested that the alkali content of the concrete be raised to 3.0% by mass of cement and that prisms are stored at 38°C.

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Table 1

List of Tests Based on Cement/Aggregate Combinations

#	TEST NAME	DESCRIPTION	REFERENCES	TIME REQUIRED
1	ASTM C 227	Mortar Bar 38°C moist	ASTM Vol. 04.02	13, 26, or 52 weeks
2	CSA A23.2 - 14A	Concrete prism 23°C, moist	CSA A23.2	12, 52 weeks
3	CSA A23.2 - 14A	Concrete prism 38°C, moist	CSA A23.2	12, 52 weeks
4	Danish T1	Mortar bar 50°C, in saturated NaCl	Chatterji, 1978; Thaulow & Olafsson, 1983	8, 20 weeks
5	Chinese Autoclave	Mortar bar 150°C for 6h in 10% KOH	Tang et al, 1983	2 days
6	German Mortar Bar	Mortar bar 40°C moist 40 x 40 mm		
7	Wetting and Drying	Concrete prism alternatively moist 16h at 23°C & dry 8h at 54°C	Scholer, 1940	300 cycles
8	ASTM C342	Mortar bar, alternative wet/dry then moist at 23°C	ASTM Vol. 04.02	52 weeks
9	NBRI Quike	Mortar bar in IN NaOH at 80°C	Oberholster and Davies, 1986	12 days
10	Duncan	Mortar bar 64°C moist	Duncan et al, 1973	12 weeks
11	Strained Quartz	Mortar bar 38°C with 5 large pieces embedded	Buck, 1983	
12	C & CA	Concrete Core 23°C, one half in IN NaOH, other in distilled water	Hobbs, 1985; Hobbs, 1988	28 days
13	Warping	Mortar bar, one side with test aggregate	Vivian et al (Woolf et al, 1948)	
14	BRE - High Alkali	Mortar bar, 38°C with 2% K_2O added	Nixon et al, 1983	
15	MTO Modified Prism	Concrete prism with 3% Na_2O eq	Rogers, 1986; Rogers, 1990	7 weeks
16	Japanese Autoclave	Mortar, 0.15-0.20 MPa steam, 5-6 h with added NaOH	Nishibayashi et al, 1986	2 days
17	Japanese GBRC Boiling	Mortar bars with 2.5% NaOH, boil for 2h	Tamura, 1986	1 day
18	Japanese Modified C 227	Mortar bar in IN NaOH at 80°C	Yashiko et al, 1986	7 days
19	Mason Jar	Mortar in mason jar at 49°C - breaks glass	Woolf and Smith, 1948	
20	Test Tube	Mortar in test tube - breaks glass	Elmhirst, 1984	
21	Opal-pat Test	Concrete put in mixed alkali, 24h, 54°C, observe gel	Stanton, 1943	1 day
22	Gel-pat Test	Mortar put in mixed alkali, 20°C, observe gel	Jones et al, 1958	4 weeks
23	Modified Concrete Prism	Concrete prism in saturated NaCl, 21°C	Smith, 1964	7,52 weeks

Table 2

List of Tests Based on Evaluatuion of Aggregate Alone

#	TEST NAME	DESCRIPTION	REFERENCE	TIME REQUIRED
1	ASTM C 586	Rock Cylinder test 13 mm diameter	ASTM Vol. 04.02	52, 104 weeks
2	Mini-Rock Prism	Rock Prism 3 x 6 x 20 mm in 2N NaOH	Grattan-Bellew, 1981	26 weeks plus
3	Osmotic Cell	Volume of gel measured in 1N NaOH with paste membrane, 22°C	Verbeck and Gramlich, 1955	5 weeks
4	Alkali-soak	Sieved Pieces in 10% NaOH, wt. loss on sieve	Stanton, 1940	
5	ASTM C 289	Quick Chemical test 25 h at 80°C in 1N NaOH	ASTM Vol. 04.02	1 week
6	ASTM C295	Petrographic analysis	ASTM Vol. 04.02	2 days
7	German Method	Mass loss in 10% NaOH for 1h at 90°C	Smolycyzk, 1973	1 day
8	Modified C 289	Only measure dssolved silica	Thaulow & Olafsson, 1983	1 week
9	Solution in KOH	% dissolution in 1N KOH, boiling for 1h	Hansen, 1944	1 day
10	Alkali-Etch	Polished sections in 10% NaOH, 50°C, 18h	Parsons and Insely, 1944	1 day
11	Rock cylinder	Rock cylinder 8 mm diameter in NaOH	Dolar-Mantuani, 1964	up to 70 weeks
12	Cell-test	Measured expansion of gel in powdered aggregate 2N NaOH, 23°C	Gillott, 1963	4 weeks
13	MTO Chemical Test	CaO/MgO vs. Al_2O_3 for alkali carbonate reactivity	Rogers, 1986	1 week
14	Danish Quick Chemical	Sand in 10N NaOH, 50°C, 20 h measure chemical shrinkage	Knudson, 1986	1 day

Table 3

Previous Studies of Variables Affecting Expansion Tests

1. **Cross-section of Specimens**
   - Davis, 1957: 25 x 25 vs. 51 x 51 mm mortar bars, 38°C, largest
   - Bakker, 1983: 20 x 20, 40 x 40, 100 x 100 mortar and concrete at 20, 40°C

2. **Size of Reactive Aggregate**
   - Woolf and Smith, 1948: 50-300 μm best for expansion
   - Duncan, 1970: C 227 expansion up when - 9.5, + 4.88 mm sizes added
   - Stanton, 1940: -30 to 80 mesh best (600 μm - 180 μm)
   - Dahms, 1975: - max expansion when 20% of aggregate 2-8 mm
   - Diamond and Thaulow, 1974: various grain sizes

3. **Porosity of Specimen**
   - Dahms, 1976: expansion up as w/c up
   - Mielenz and Witte, 1948: expansion influenced by air and cement contents
   - Stanton, 1951: expansion up as w/c or flow goes up

4. **Alkali Concentration**
   - Hobbs, 1980: deleterious if alkali loading greater than 3.0 kg/m^3
   - Chatterji, 1986: NaCl accelerates expansion at 50°C
   - Oberholster and Davies, 1986: 0.25 to 20 N NaOH, 1.0 N is best
   - Duncan, 1973-1: 0.34 to 1.40 Na_2Oeq
   - Blanks and Meissner, 1946: - 2% $CaCl_2$ increases expansion
     - finer cement increases expansion

5. **Ratio of K_2O to Na_2O**
   - Grattan-Bellew and Litvan, 1976: Na_2O more expansion
   - Sprung, 1973: K_2O reacts earlier, Na_2O gives more expansion
   - Maketa et al, 1986: Na_2 gives more expansion

6. **Temperature**
   - Locher, 1973: 20°C, 40°C, 60°C. 40°C is best for expansion
   - Bakker, 1983: 40°C more than 20°C
   - Scholer, 1949: 49°C, 54°C, 71°C for cyclic test
   - Oberholster and Davies, 1986: 70°C, 80°C, 90°C. 80°C is best
   - Duncan, 1973: 23°C, 38°C, 52°C, 64°C. 64°C is best
   - Tang, 1983: Autoclave 140°C to 300°C. 150°C is best
   - Carlson, 1950: 43°C alright but 65°C created quartz
   - Banks and Meissner, 1946: suggested caution in raising temperature
   - Hooton, 1986: Beaharnois agg. expanded at 38°C but not 23°C in concrete.

Table 4

Problems Reported for Test Methods

A) Problems of Over-Magnification:

Hooton, 1990b:	- 2% Na_2O in mix expanded good aggregate - ASTM C 342 test expanded good aggregate - ASTM C 289 test showed good aggregate as potential deteriorations
Smolczyk, 1976:	- non-reactive rocks will expand if alkali concentration is too high
Scholer, 1949:	- wetting and drying tests can expand non-reactive shales
Blanks and Meissner, 1946:	- adding 0.75% NaOH reduced expansions of C 227 in some cases, depending on particle size.

B) Problems of Insensitivity:

RE: ASTM C-289	- Oberholster and Davies, 1986 - Grattan-Bellew and Litvan, 1976 - Hooton, 1985, 1989, 1990b - Bakker, 1983 - Duncan, 1973 - Mielenz and Benton, 1957 - Smolczyk, 1973.
RE: ASTM C-227	- Hooton, 1986b: effects of variation of RH in containers - Oberholster, 1986: poor reproducibility - Grattan-Bellew and Litvan, 1976: feldspathic quartzite did not expand but concrete prisms did - Smolczyk, 1976: at 40 C and high alkali content, even good quartz sand will react. - Rogers and Hooton, 1989: effects of alkali leaching.

Table 5

Composition of Test Cements

CEMENTING MATERIAL	NORMAL PORTLAND CEMENT (Ontario Hydro CLG9317)	ST. LAWRENCE CEMENT (MTO 89-F-72)
OXIDES (%)		
CaO	62.2	61.85
SiO_2	20.7	20.35
Al_2O_3	5.8	6.20
MgO	2.97	2.38
Fe_2O_3	2.64	2.04
SO_3	3.11	2.98
K_2O	1.18	1.06
Na_2O	0.39	0.19
LOI	1.72	2.95
Industrial Residue		1.10
C_3A	10.7	13.0
Na_2O eq	1.17	0.89
RELATIVE DENSITY	3.12	-
BLAINE (m^2/kg)	359	425

Table 6

Aggregate Description and Field Performance in Concrete

#	Aggregate Name	Description	Reactive Components	Field Performance
1	Nelson stone	quarried dolostone	none	Excellent - > 30 years
2	Ottawa sand (Illinois)	pure quartz sand	none	None
3	Fleming sand	quarried granite	strained quartz	None[4]
4	Guelph sand	carbonate sand	0.2% chert	Excellent - > 30 years
5	Paris sand	carbonate sand	0.3% chert	Excellent - > 30 years
6	Neyes sand	siliceous sand	2.5% chert	Reactive[2]
7	Paris stone	carbonate gravel	1.6% chert	Excellent - > 30 years
8	Grant stone	siliceous gravel	27% argillite, greywacke, sandstone	Reactive[1]
9	Natural sand (Michigan)	siliceous sand	7.4% chert	Reactive[1]
10	Sudbury stone	siliceous gravel	75% argillite, greywacke, sandstone	Reactive[1]
11	Lower Notch stone	quarried meta-sediments	98% argillite, greywacke, sandstone	Reactive[3]
12	Spratt stone	quarried limestone	< 5% chalcedony	Reactive[1]

Footnotes:

1. Alkali reaction identified in many structures.
2. Alkali reaction identified in part of one 30-year old structure.
3. Alkali reaction identified in small part of one 20-year old dam (but the use of fly ash has prevented reaction in most of this structure).
4. Petrographically similar to alkali-silica reactive granite in 70-year structure.

TABLE 7: DESCRIPTION OF AGGREGATES USED FOR PHASE II NBRI TESTING.

Map No.	Sample No.	Source Name and Location	MAIDB No.	Aggregate Type Coarse	Aggregate Type Fine	Remarks
1	89-40057	Miller Const., Wawa	M41-22	X		igneous & metamorphic sand
1	89-40058	Miller Const., Wawa	M41-22		X	as above
2	89-40059	United Aggs., Ottawa	O5-72	X		Oxford dolostone quarry
3	89-40060	Francon, Ottawa	O5-05	X		Bobcaygeon limestone quarry
4	89-40061	Burnside S & G, Ottawa	K3-76		X	
5	89-40062	Batiuk Pit, Kenora	K4-013		X	igneous & metamorphic gravel
5	89-40063	Batiuk Pit, Kenora	K4-013	X		as above
6	89-40064	A.B. Mclean, Sault Ste Marie	S10-103	X		dredged igneous gravel
6	89-40065	A.B. McLean, Sault Ste Marie	S10-103		X	as above
7	89-40066	United Aggs., Caledon	B10-121	X		carbonate gravel
7	89-40067	United Aggs., Caledon	B10-121		X	carbonate sand
8	89-40068	T.C.G., Fonthill	N03-026		X	carbonate sand
9	89-40069	Cayuga Materials, Dunnville	D05-020			quarried Falkirk dolostone
10	89-40070	C.B.M., Newmarket	N02-075	X		carbonate gravel
11	89-40071	Sweets S & G, Seeleys Bay	G02-92		X	igneous & metamorphic sand

TABLE 7 (cont'd)

Map No.	Sample No.	Source Name and Location	MAIDB No.	Aggregate Type Coarse	Aggregate Type Fine	Remarks
12	89-40072	Huron G, Chatham	C08-003		X	high chert & shale content
13	89-40073	Huron Conc., Seaforth	S04-010	X		carbonate gravel
13	89-40074	Huron Conc., Seaforth	S04-010		X	carbonate sand
14	89-40075	Johnston, Komoka, London	S09-134		X	carbonate sand
15	89-40076	Whitechurch S & G, Wingham	W09-164		X	carbonate sand
16	89-40077	LTL, Thunder Bay	T21-063	X		quarried diabase
17	89-40078	Kam Aggs., Thunder Bay	S20-037		X	igneous & metamorphic sand
17	89-40079	Kam Aggs., Thunder Bay	S20-037	X		as above
17	89-40080	" " "	" "	X		duplicate sample
15	89-40081	Whitechurch S & G, Wingham	W09-164	X		carbonate gravel
18	89-40082	C.B.M. (Mathews), London	L07-161	X		carbonate gravel
19	89-40083	Hoffman, Petawawa	P06-035	X		igneous & metamorphic gravel
19	89-40084	Hoffman, Petawawa	P06-035		X	igneous & metamorphic sand
20	89-40085	Smith, Braeside, Arnprior	A05-066	X		Bobcaygeon limestone quarry
21	89-40086	Smith (Miller), Renfrew	R03-015		X	igneous & metamorphic sand

TABLE 7 (cont'd)

Map No.	Sample No.	Source Name and Location	MAIDB No.	Aggregate Type Coarse	Aggregate Type Fine	Remarks
22	89-40087	Deschenes, Aylmer, P.Q	O05-99	X		Bobcaygeon limestone quarry
23	89-40088	Dufferin Aggs., Aylmer, P.Q.	O05-10	X		Bobcaygeon limestone quarry
24	89-40089	Hume, Parkhill	P04-123		X	carbonate sand with chert
25	89-40090	Labelle, Cochrane	C24-20	X		igneous & metamorphic gravel
26	89-40091	Grant, Cobalt	C23-27		X	igneous & metamorphic sand
25	89-40092	Labelle, Cochrane	C24-17		X	igneous & metamorphic sand
27	89-40093	Standard (Bomarc), North Bay	N05-115		X	igneous & metamorphic sand
28	89-40094	Northfield S & G, North Bay	N05-028		X	igneous & metamorphic sand
29	89-40095	Fisher Block, Falconbridge	C03-019		X	igneous & metamorphic sand
30	89-40096	Rainbow Conc., Elliott Lake	R25-031	X		igneous & metamorphic gravel
31	89-40097	Sauble Concrete, Massey	S31-021		X	igneous & metamorphic

TABLE 7 (cont'd)

Map No.	Sample No.	Source Name and Location	MAIDB No.	Aggregate Type Coarse	Aggregate Type Fine	Remarks
32	89-40098	Nomad S&G, Brighton	T07-215	X		carbonate gravel
32	89-40099	" " "	T07-215	X		carbonate gravel
32	89-40100	" " "	T07-215		X	carbonate sand

Table 8

ASTM C 227 and NBRI Test Expansions (%)

#	Aggregate Name	ASTM C227						NBRI Method			
		MTO Container			Bagged			14 d	16 d	28 d	56 d
		6m	12m	18m	6m	12m	18m				
1	Nelson	.019	.034	.036	.021	.036	.040	.009	.012	.020	.039
2	Ottawa	.023	.022	.026	.019	.021	.023	.038	.038	.053	.139
3	Fleming	.005	.021	.019	.021	.039	.040	.038	.046	.086	.205
4	Guelph	.029	.039	.014	.029	.042	.049	.077	.093	.177	.297
5	Paris Sand	.023	.039	.049	.029	.047	.050	.122	.153	.306	.399
6	Neyes	.024	.024	.030	.020	.020	.028	.118	.164	.369	.513
7	Paris	.012	.025	.020	.025	.045	.044	.144	.175	.293	.336
8	Grant	.011	.024	.014	.030	.054	.057	.143	.185	.423	.533
9	Natural	.023	.023	.031	.041	.048	.052	.172	.213	.494	.525
10	Sudbury	.022	.031	.032	.036	.062	.080	.221	.266	.466	.736
11	Lower Notch	.017	.032	.035	.036	.077	.094	.282	.326	.540	.746
12	Spratt	.046	.055	.058	.166	.222	.234	.309	.356	.626	.956

Table 9

Duncan, Danish Salt and Japanese Rapid Test Expansions (%)

#	Aggregate Name	Duncan Test				Danish Salt Test				Japanese Rapid Test 4% NaOH
						in Sat. NaCl			Corrected	
		12w	16w	26w	52w	8w	20w	52w	20w	
1	Nelson	.033	.023	.025	.028	.003	.013	.005	.001	.034
2	Ottawa	.027	.027	.029	.050	-	-	-	-	.033
3	Fleming	.040	.044	.053	.072	.022	.054	.062	.008	.047
4	Guelph	.032	.034	.036	.042	.003	.007	.012	.007	.060
5	Paris Sand	.036	.035	.037	.047	.008	.019	.019	.005	-
6	Neyes	.035	.042	.061	.084	.022	.027	.027	.003	.057
7	Paris	.035	.034	.037	.049	.017	.026	.028	.007	.060
8	Grant	.029	.033	.041	.059	-	-	-	-	.043
9	Natural	.025	.026	.025	.028	-	-	-	-	.054
10	Sudbury	.057	.055	.063	.079	.016	.049	.052	.002	.044
11	Lower Notch	.023	.026	.033	.030	.016	.023	.053	.008	.069
12	Spratt	.068	.071	.081	.104	.021	.054	.072	.013	.225
13	Pyrex Glass	.227	.224	.233	.240	-	-	-	-	-

*corrected by subtracting expansions of companion bars in water

Table 10

Effect of Alkali Addition on Japanese Rapid Test Expansions

Aggregate	% Added Na_2O		
	3.0	3.5	4.0
Spratt (reactive)	0.090	0.150	0.225
Nelson (non-reactive)	0.031	0.034	0.034

Average expansion of 3 bars

NEW ALKALI REACTIVITY PROJECT

Table 11: Concrete Prism Design Data

LAB. NO.	MIX NO.	TYPE OF AGG. COMB. C. A. & F. A.	C.A. Kg/M3	F.A. Kg/M3	CEM. Kg/M3	EFF. W/C RATIO	CEM. TYPE	TOTAL ALK.	ALK. Na2O EQUIV.	SLUMP mm
L-800/85	1	Fleming + Guelph	1107	804	310	0.53	CCL BATH	0.91	3.00	75
L-778/87	2	Spratt + Guelph	1093	826	309	0.53	CCL BATH	0.93	3.00	70
L-786/87	3	Nelson + Guelph	1042	876	308	0.56	CCL BATH	0.93	3.00	75
L-797/88	4	Spratt + Guelph	1093	792	411	0.41	ONT. HYDRO	1.17	1.25	30
L-798/88	5	Sudbury + Guelph	1124	806	395	0.41	ONT. HYDRO	1.17	1.25	145
L-799/88	6	Nelson + Guelph	1080	729	399	0.41	ONT. HYDRO	1.17	1.25	160
L-804/88	7	Fleming + Guelph	1100	720	402	0.41	ONT. HYDRO	1.17	1.25	100
L-805/88	8	Grant + Guelph	1146	723	405	0.41	ONT. HYDRO	1.17	1.25	80
L-809/88	9	Paris + Guelph	1206	607	403	0.41	ONT. HYDRO	1.17	1.25	170
L-810/88	10	Nelson + Paris	1080	716	405	0.41	ONT. HYDRO	1.17	1.25	50
L-817/88	11	Nelson + Neyes	1065	723	400	0.41	ONT. HYDRO	1.17	1.25	95
L-818/88	12	Nelson + Natural	1080	707	402	0.41	ONT. HYDRO	1.17	1.25	180
L-819/88	13	Maple Ridge + Gue.	1129	721	401	0.41	ONT. HYDRO	1.17	1.25	125
L-825/88	14	McNulty + Guelph	1177	719	400	0.41	ONT. HYDRO	1.17	1.25	170
L-826/88	15	Beauceville + Guel.	1095	803	403	0.41	CCL BATH	0.80	1.25	95
L-830/88	16	Nelson + Neyes	1065	723	297	0.50	CCL BATH	0.80	3.00	185
L-831/88	17	Nelson + Natural	1080	707	303	0.50	CCL BATH	0.80	3.00	170
L-838/88	18	Maple Ridge + Gue.	1129	721	301	0.55	CCL BATH	0.80	3.00	25
L-839/88	19	McNulty + Guelph	1177	719	306	0.52	CCL BATH	0.80	3.00	85
L-840/88	20	Beauceville + Guel.	1095	803	309	0.50	CCL BATH	0.80	3.00	80
L-864/88	21	Hudson + Guelph	939	899	408	0.40	CCL BATH	0.80	1.25	100
L-865/88	22	Hudson + Guelph	939	992	307	0.55	CCL BATH	0.80	3.00	70
L744/89	23	Lower Notch + Guelph	1109	838	307	0.55	CCL BATH	0.80	3.00	90
L743/89	24	Lower Notch + Guelph	1109	744	408	0.41	ONT. HYDRO	1.00	1.25	130
L745/89	25	Adams Mine + Guelph	1159	930	305	0.55	CCL BATH	0.80	3.00	90
L746/89	26	Adams Mine + Guelph	1159	836	401	0.41	ONT. HYDRO	1.00	1.25	170
L742/89	27	Springhill + Guelph	1070	895	306	0.55	CCL BATH	0.80	3.00	100
L741/89	28	Springhill + Guelph	1070	800	408	0.41	ONT. HYDRO	1.00	1.25	125

Table 12

German Sand Test Results

#	Aggregate Name	Alkali Soluble Fraction	
		1.15 to 2.3 mm Fraction %	2.3 to 4.75 mm Fraction %
1	Nelson	0.38	1.81
2	Ottawa	-	-
3	Fleming	0.25	0.48
4	Guelph	0.10	0.55
5	Paris Sand	0.04	0.50
6	Neyes	0.36	0.32
7	Paris	0.06	0.80
8	Grant	0.17	0.24
9	Natural	-	0.18
10	Sudbury	0.25	0.30
11	Lower Notch	0.06	0.20
12	Spratt	0.25	0.94
12	Pyrex Glass	0.01	0.27
14	Pittsburgh	0.55	0.60

Table 13
ADDITIONAL NBRI TEST EXPANSIONS

MTO No.	Sample Name	Expansion (%)			
		14 Days	16 Days	28 Days	56 Days
-	Springhill, N.S.	.420E	.474	.671	1.016
-	Spratt, Ont.	.270	.342	.566	1.019
-	Sudbury, Ont.	.282	.319	.467	.650
88-40021	Colorusso N.Y.	-	.328	.530	.756
88-40026	Warner*, P.A.	.207	.231	.365E	.552
88-40026	Warner**, P.A.	.219	.252	.399	.563
88-40032	Maple Ridge, Ont.	.215	.238	.394	.610
88-40082	MacNulty, N.B.	.229E	.251	.407	.597
88-40098	Beauceville P.Q.	.357	.386	.522E	.688
88-40064	Lower Notch, Ont.	.206E	.225	.364	.561
88-40065	Adam's Mine***, Ont.	.241	.289	.424	.625
88-40027	Adam's Mine****, Ont.	.312	.339E	.505E	.751

* w/c = 0.500 Flow = 93
** w/c = 0.545 Flow = 110
E = Estimated by interpolation
*** w/c = 0.500, C1-1989 cement
**** w/c = 0.500, C169317 cement

Table 14
PHASE 2 NBRI TEST EXPANSIONS

Location	MTO No.	Expansion (%)			
		14 Days	16 Days	28 Days	56 Days
1	89-40057	.085	.090	.120	.201
1	89-40058	.185	.217	.283	.430
2	89-40059	.016	.021	.029	.048
3	89-40060	.028E	.028	.077	.102
4	89-40061	.046	.071	.125	.193
5	89-40062	.056	.080	.110E	.184
5	89-40063	.030E	.037	.074	.119
6	89-40064	.116	.147E	.268	.449
6	89-40065	.105	.135	.270	.475
7	89-40066	.193E	.234	.300	.400
7	89-40067	.168	.172E	.320	.441
8	89-40068	.211	.259	.290	.620
9	89-40069	.028E	.026	.047	.053
10	89-40070	.086	.095	.131	.164
11	89-40071	.044	.057	.096	.214
12	89-40072	.315	.384	.605	.747
13	89-40073	.091	.099	.135	.154
13	89-40074	.102	.118	.198	.230
14	89-40075	.111	.145	.297	.473
15	89-40076	.055	.078	.163	.256
16	89-40077	.075E	.089	.173	.206
17	89-40078	.010	.030E	.071	.239
17	89-40079	.155	.206	.376	.520
17	89-40080	.150	.173E	.222	.407

E = Estimated by linear interpolation

Table 14 cont'd
PHASE 2 NBRI TEST EXPANSIONS

Location	MTO No.	Expansion (%)			
		14 Days	16 Days	28 Days	56 Days
15	89-40081	.096	.118E	.178	.243
18	89-40082	.081E	.098	.162	.224
19	89-40083	.033E	.043	.072	.149
19	89-40084	.042	.043	.076	.169
20	89-40085	.038	.047	.051	.095
21	89-40086	.050	.070	.080	.124
22	89-40087	.037	.042	.055	.104
23	89-40088	.058	.090	.141	.185
24	89-40089	.177E	.217	.343	.556
25	89-40090	.094	.105	.160	.259
26	89-40091	.207	.258	.368	.501
25	89-40092	.216	.244	.388	.556
27	89-40093	.058	.091	.142	.213
28	89-40094	.063	.069	.117	.235
29	89-40095	.269	.297	.418	.631
30	89-40096	.041	.055	.103	.168
31	89-40097	.114	.133	.212	.315
32	89-40098	.089	.102		
32	89-40099	.090	.104		
32	89-40100	.069	.085		

Table 15

Influence of Test Variations on NBRI Expansions

#	Aggregate Name	14 Day Expansions (%)			W/C for constant flow
		Constant Flow	W/C = 0.50	Unwashed Aggregate Constant Flow	
5	Paris Sand	.153	.197	.147	.46
7	Paris	.175	.163	.151	.54
10	Sudbury	.266	.255	.275	.53
11	Lower Notch	.326	.403	-	.54
12	Spratts	.356	.375	.441	.54

Table 16
FIELD PERFORMANCE AND EXPANSIONS IN VARIOUS TESTS FOR AAR

Reactive Component or Rock Type	Agg	FIELD PERF.	12 month CONCRETE PRISM						MORTAR BARS					
			1.25%Na_2O			3.0%Na_2O			NBRI			C227 (bagged)		
			23°C >.025	23°C SALT >.025	38°C >.04	23°C >.025	23°C SALT >.025	38°C >.04	16D >.15	28D >.33	56D >.48	6m >.05	12m >.10	18m >.10
CHALCEDONY	SPRATT	X	.062	.056	.134	.085	.133	.193	.356	.626	.956	.166	.224	.234
ARGILLITE	SUDBURY	X	.012	.021	.021	.019	.021	.174	.266	.466	.736	.036	.062	.080
STRAINED QUARTZ	FLEMING	?	.023	.024	.022	-	-	.077	.046	.086	.205	.021	.039	.040
ARGILLITE	GRANT	X	.008	.014	.017	-	-	.138	.185	.423	.533	.030	.054	.057
CHERT	PARIS GR	√	.017	.025	.015	-	-	-	.175	.293	.336	.025	.045	.044
CHERT	PARIS SAND	√	.015	.020	.018	-	-	-	.153	.306	.399	.029	.047	.050
CHERT	NEYES	?	.016	.024	.004	.010	.017	.013	.164	.369	.513	.020	.020	.028
CHERT	NATURAL	X	.015	.025	.018	.015	.014	.059	.213	.494	.525	.041	.048	.052
ARGILLITE	MAPLE RIDGE	X	.014	.020	.020	.013	.016	.040	.238	.394	.610	.037*	.064	-
ARG., CHERT, ARKOSE	McNULTY	X	.018	.022	.030	.019	.024	.129	.251	.407	.597	.051*	.119	-
RHYOLITE	BEAUCEVILLE	X	.037	.040	.142	.134	.150	.188	.386	.532	.688	.245*	.337	-
SILICEOUS LMST.	COLARUSSO	X	.005	.020	.010	.104	.120	.209	.328	.530	.756	.188*	.269	-
ARGILLITE	SPRINGHILL	X	.016	.021	.105	.078	.113	.209	.474	.671	1.016	.229*	.359	-
ARGILLITE	L. NOTCH	X	.012	.026	.047	.015	.018	.123	.326	.540	.746	.036	.077	.094
TACONITE (CHERT)	ADAMS MINE	X	.023	.022	.083	.026	.030	.128	.289	.424	.625	.113*	.196	-
NONE	NELSON	√	.015	.019	.015	.021	.020	.027	.012	.020	.039	.021	.036	.040
CHERT	GUELPH SAND	√	.015	.019	.015	.021	.020	.027	.093	.177	.297	.029	.042	.049

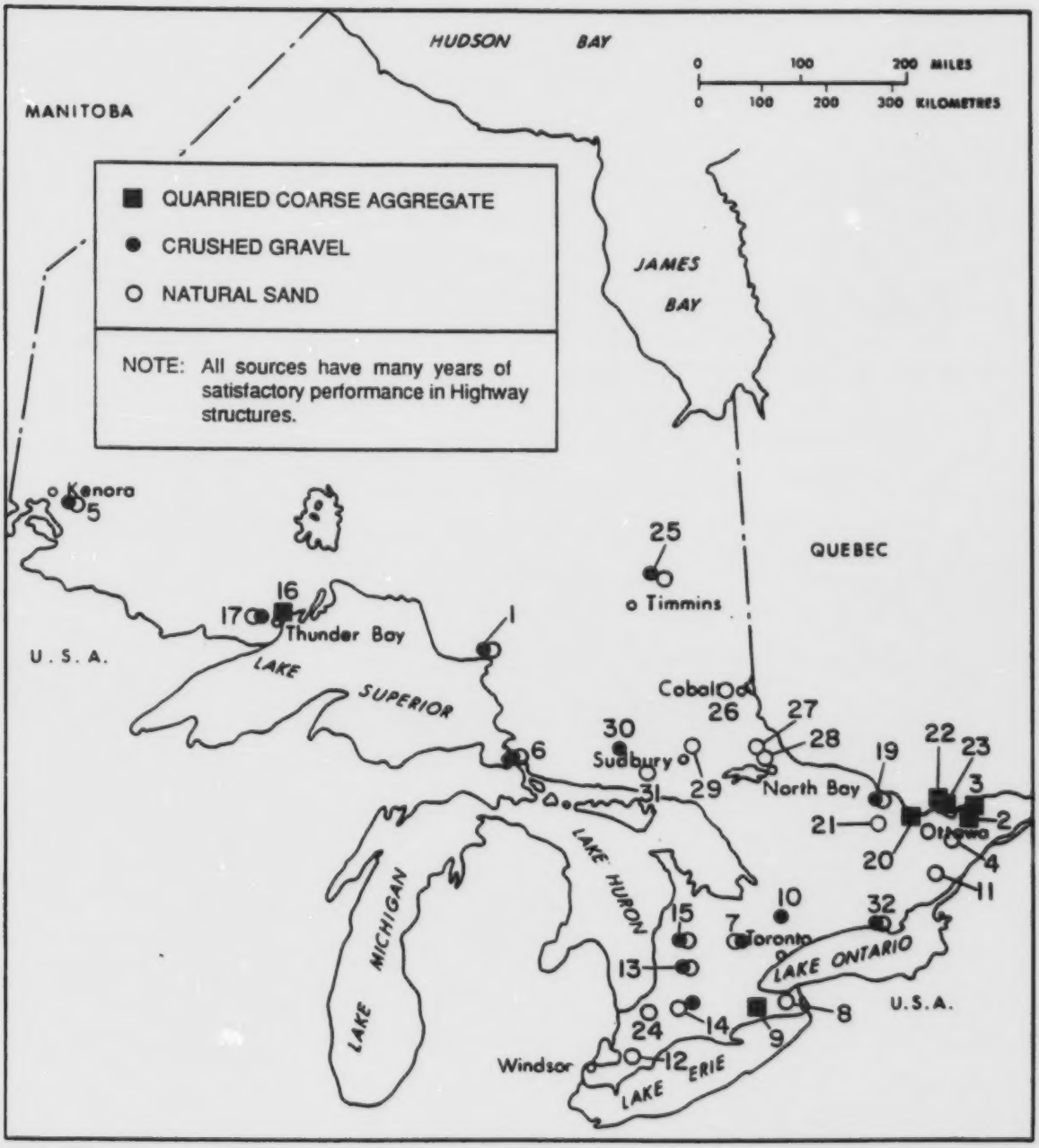
√ = INNOCUOUS X = REACTIVE * = TESTED AT MTO LABS.

Table 17
FIELD PERFORMANCE AND RANKINGS IN VARIOUS TESTS FOR AAR

			12 month CONCRETE PRISM						MORTAR BARS					
			1.25%Na_2O			3.0%Na_2O			NBRI			C227 (bagged)		
Reactive Component or Rock Type	Agg	FIELD PERF.	23°C >.025	23°C SALT >.025	38°C >.04	23°C >.025	23°C SALT >.025	38°C >.04	16D >.15	28D >.33	56D >.48	6m >.05	12m >.10	18m >.10
CHALCEDONY	SPRATT	X	X	X	X	X	X	X	X	X	X	X	X	X
ARGILLITE	SUDBURY	X	√	√	√	√	√	X	X	X	X	√	√	√
STRAINED QUARTZ	FLEMING	?	√	√	√	-	-	X*	√	√	√	√	√	√
ARGILLITE	GRANT	X	√	√	√	-	-	X	X*	X	X	√	√	√
CHERT	PARIS GR	√	√	.025*	√	-	-	-	X*	√	√	√	√	√
CHERT	PARIS SAND	√	√	√	√	-	-	-	X	√	√	√	√	√
CHERT	NEYES	?	√	√	√	√	√	√	X	X	X	√	√	√
CHERT	NATURAL	X	√	.025	√	√	√	X	X	X	X	√	√	√
ARGILLITE	MAPLE RIDGE	X	√	√	√	√	√	.040	X	X	X	√	√	-
ARG., CHERT, ARKOSE	McNULTY	X	√	√	√	√	√	X	X	X	X	X	X	-
RHYOLITE	BEAUCEVILLE	X	X	X	X	X	X	X	X	X	X	X	X	-
SILICEOUS LMST.	COLARUSSO	X	√	√	√	X	X	X	X	X	X	X	X	-
ARGILLITE	SPRINGHILL	X			X			X	X	X	X	X	X	-
ARGILLITE	L. NOTCH	X			X			X	X	X	X	√	√	√
TACONITE (CHERT)	ADAMS MINE	X			X			X	X	X	X	X	X	-
NONE	NELSON	√	√	√	√	√	√	√	√	√	√	√	√	√
CHERT	GUELPH SAND	√	√	√	√	√	√	√	√	√	√	√	√	√

√ = PASS X = FAIL * = OVEREMPHASIZED

FIG. 1
MTO APPROVED AGGREGATE SOURCES TESTED IN PHASE 2



Note: 1989 Series: Numbers refer to Aggregates Listed in Table 7

FIG. 2

COMPARISON OF 18 MONTH ASTM C 227 EXPANSIONS TO 16 DAY NBRI EXPANSIONS

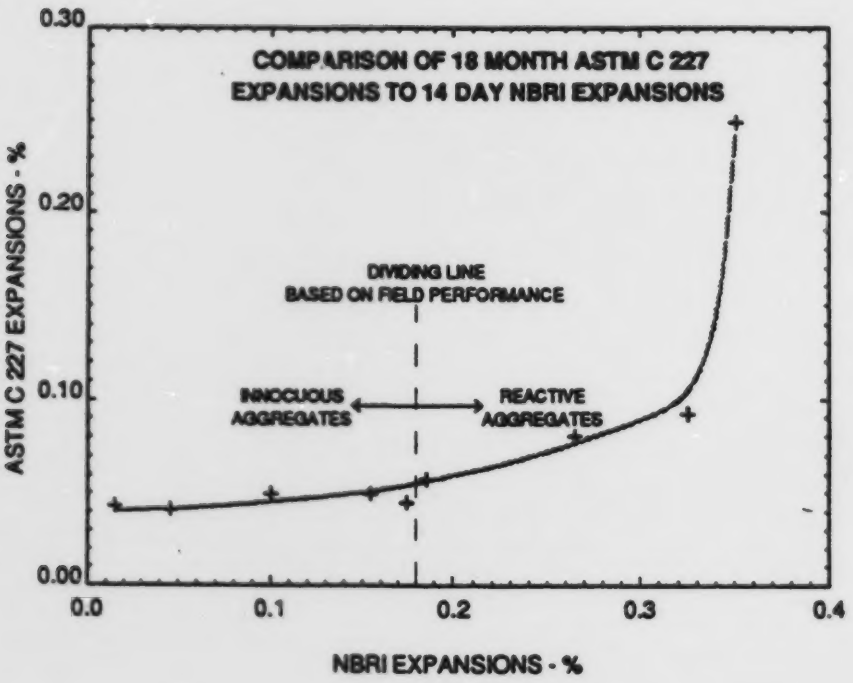
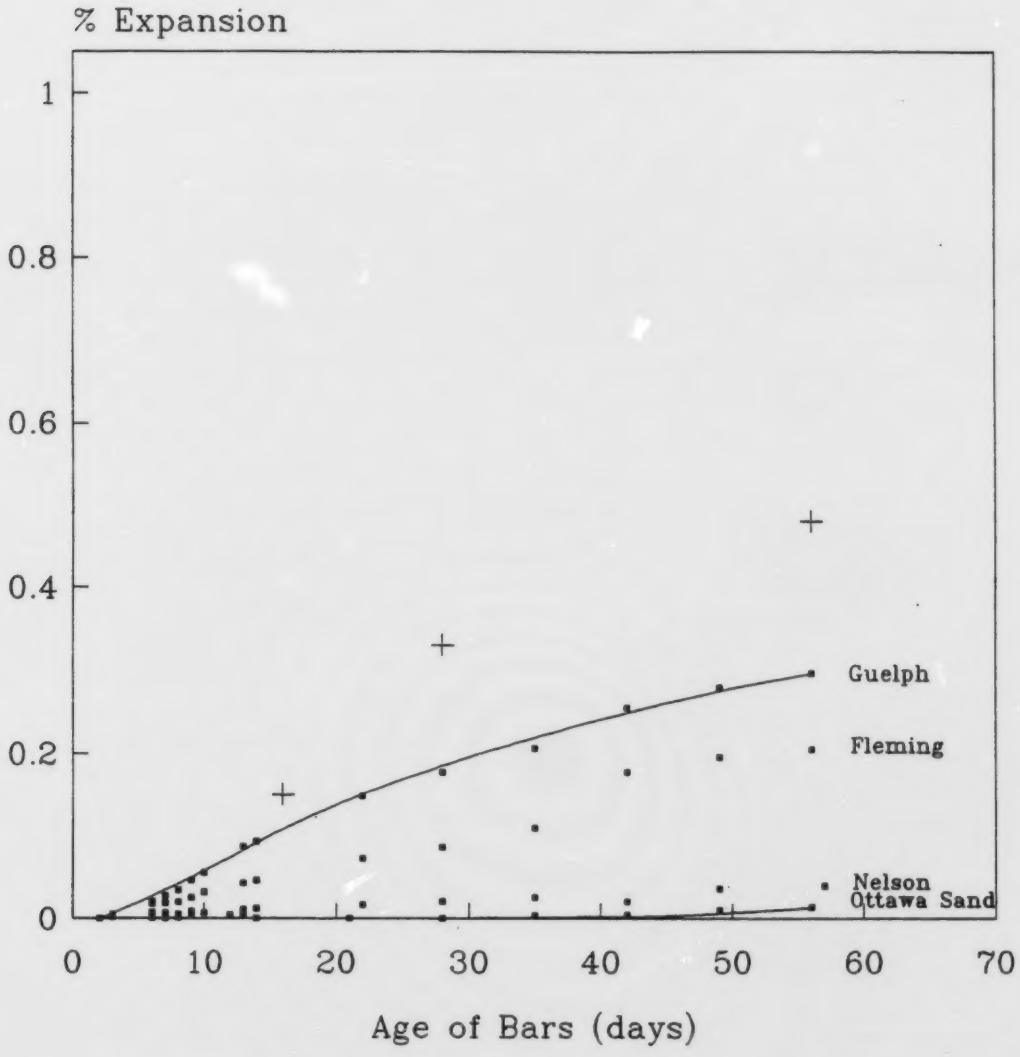


FIG. 3a

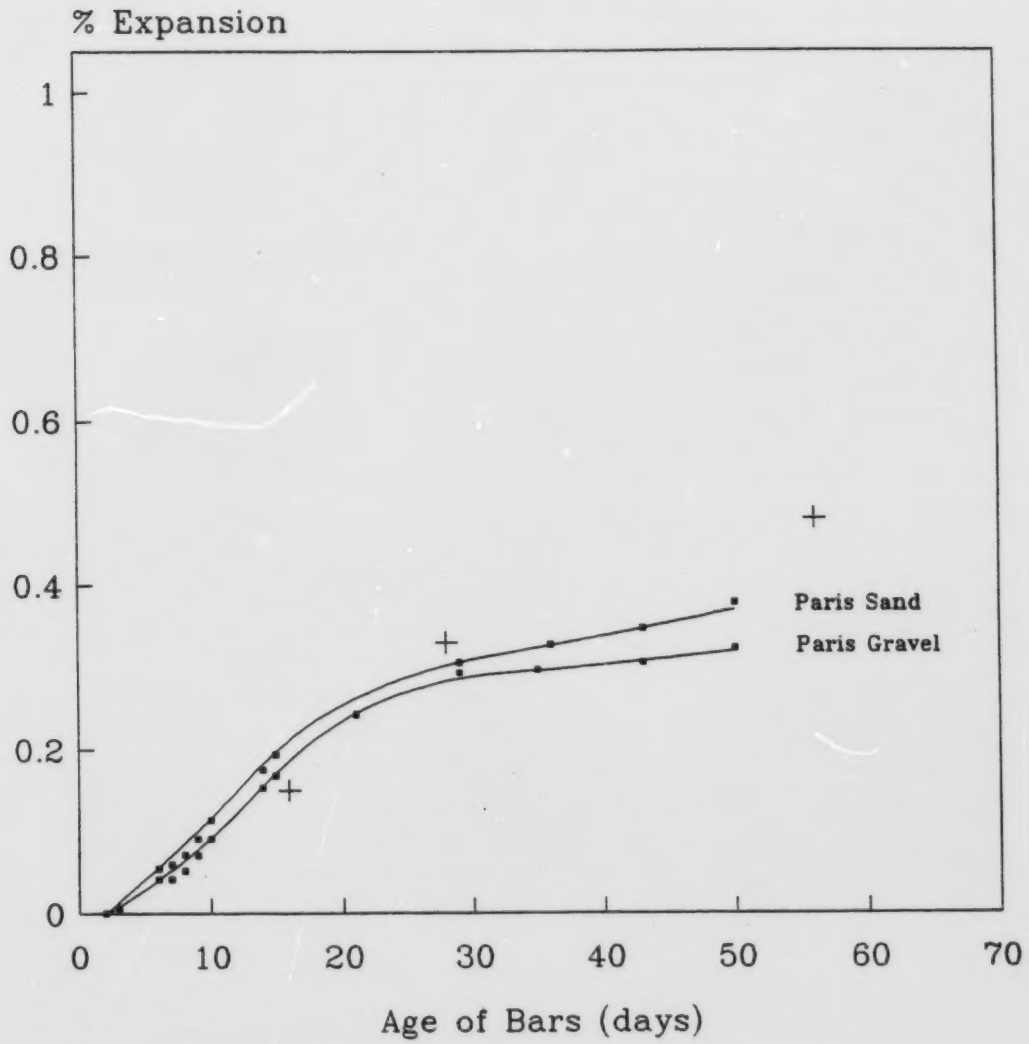
NBRI TEST – PHASE I
Innocuous Aggregates



+ Expansion Limits
Note: 4 innocuous aggregates plotted

FIG. 3b

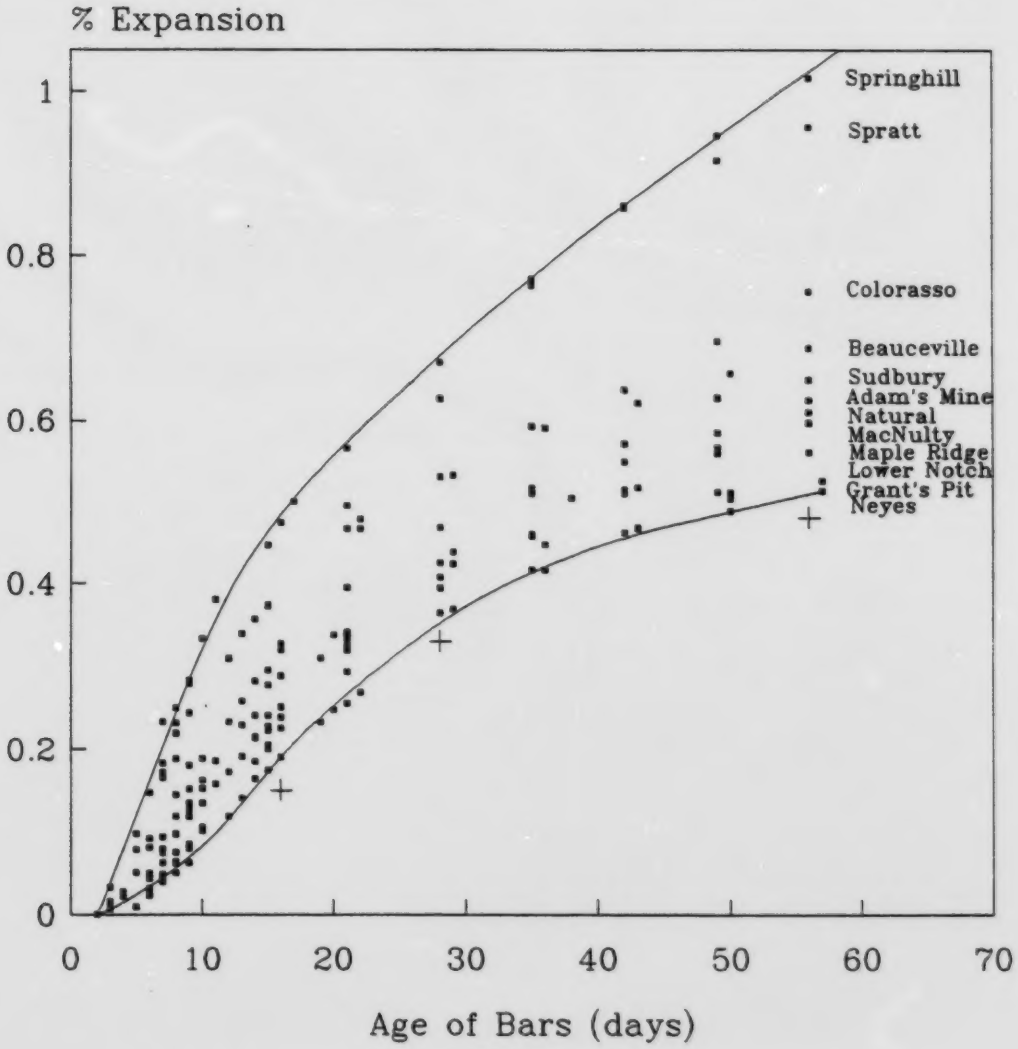
NBRI TEST – PHASE I
Marginal (but acceptable) Aggregates



+ Expansion Limits
Note: 2 marginal aggregates plotted

FIG. 3c

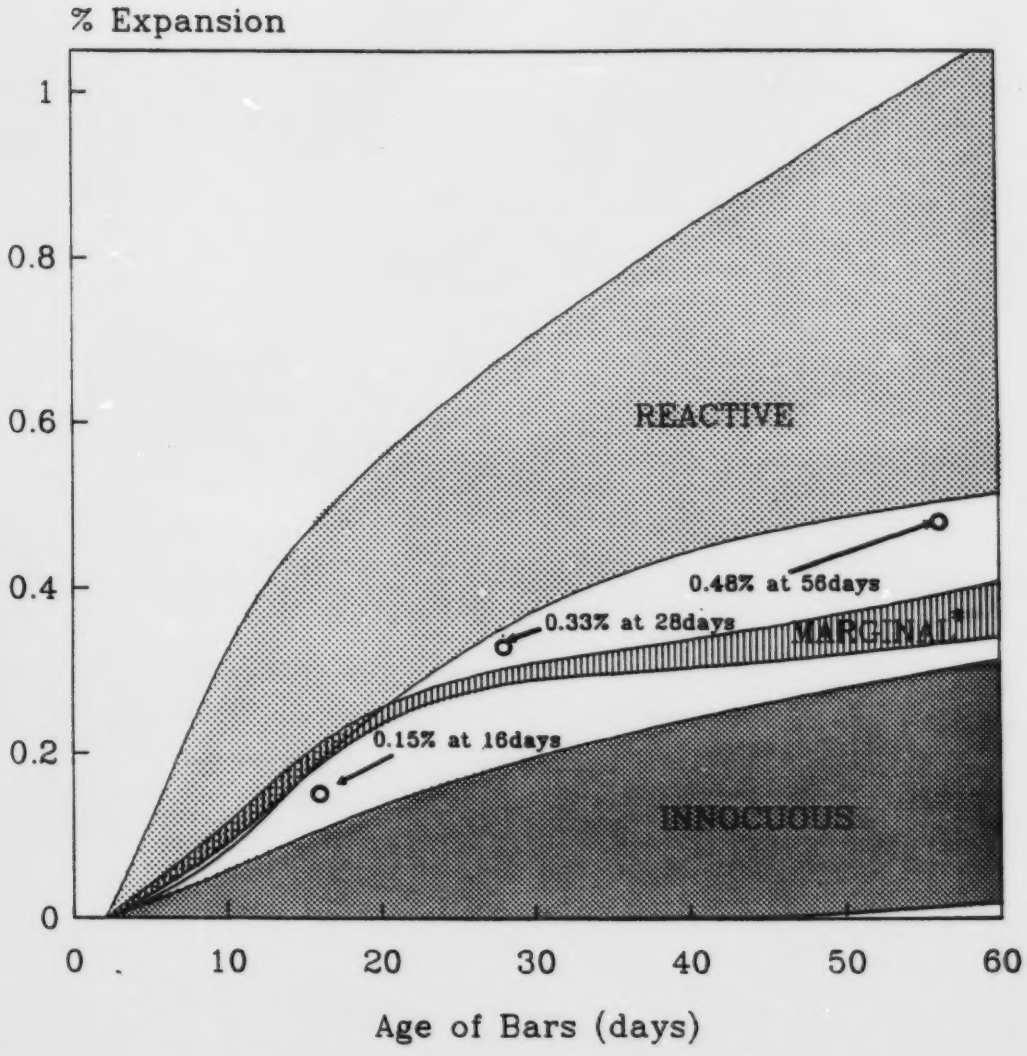
NBRI TEST – PHASE I
Reactive Aggregates



+ Expansion Limits
Note: 12 reactive aggregates plotted

FIG. 4

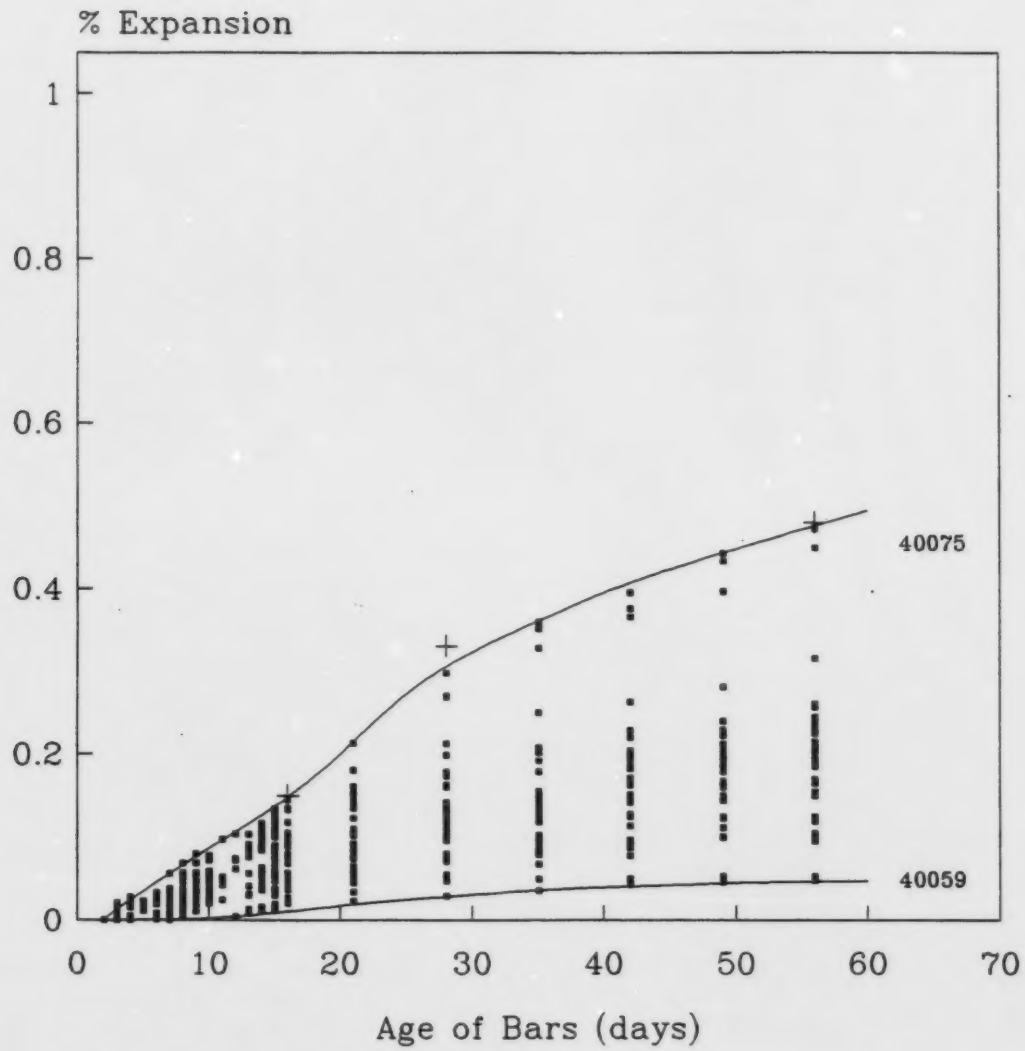
NBRI TEST – PHASE I
Reactivity Zones



+ Expansion Limit
* MARGINAL, but acceptable

FIG. 5a

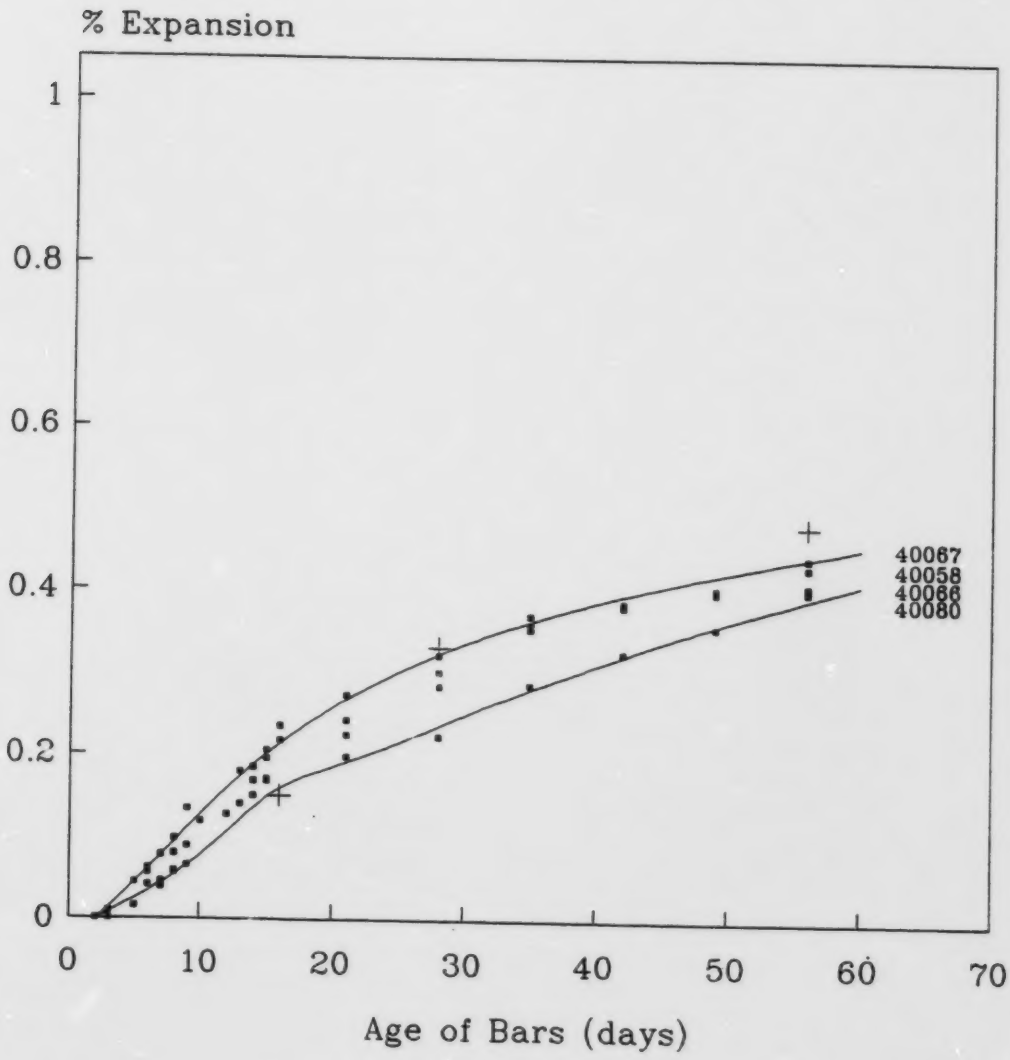
NBRI TEST – PHASE II
Innocuous Aggregates



+ Expansion Limit
Note: 30 innocuous aggregates plotted

FIG. 5b

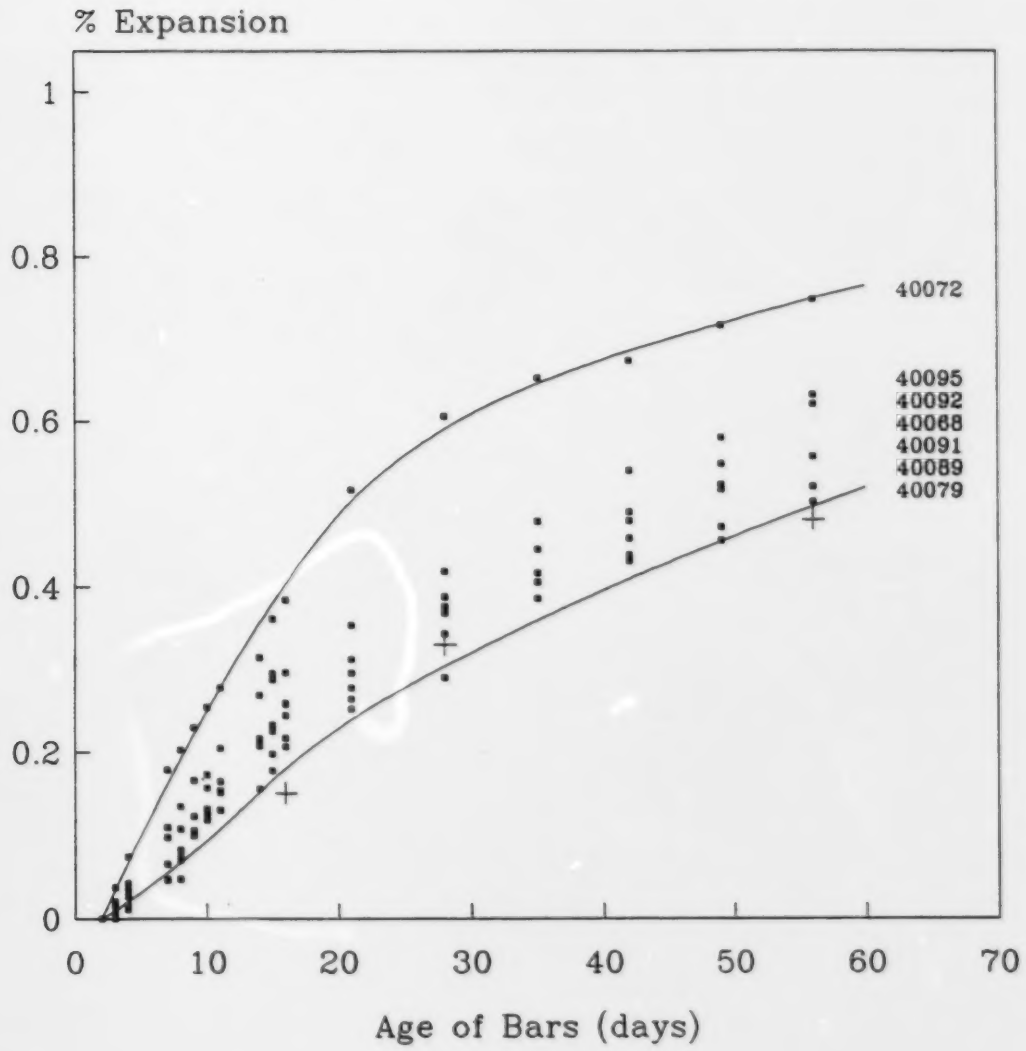
NBRI TEST – PHASE II
Marginal (but acceptable) Aggregates



+ Expansion Limit
Note: 4 marginal aggregates plotted

FIG. 5c

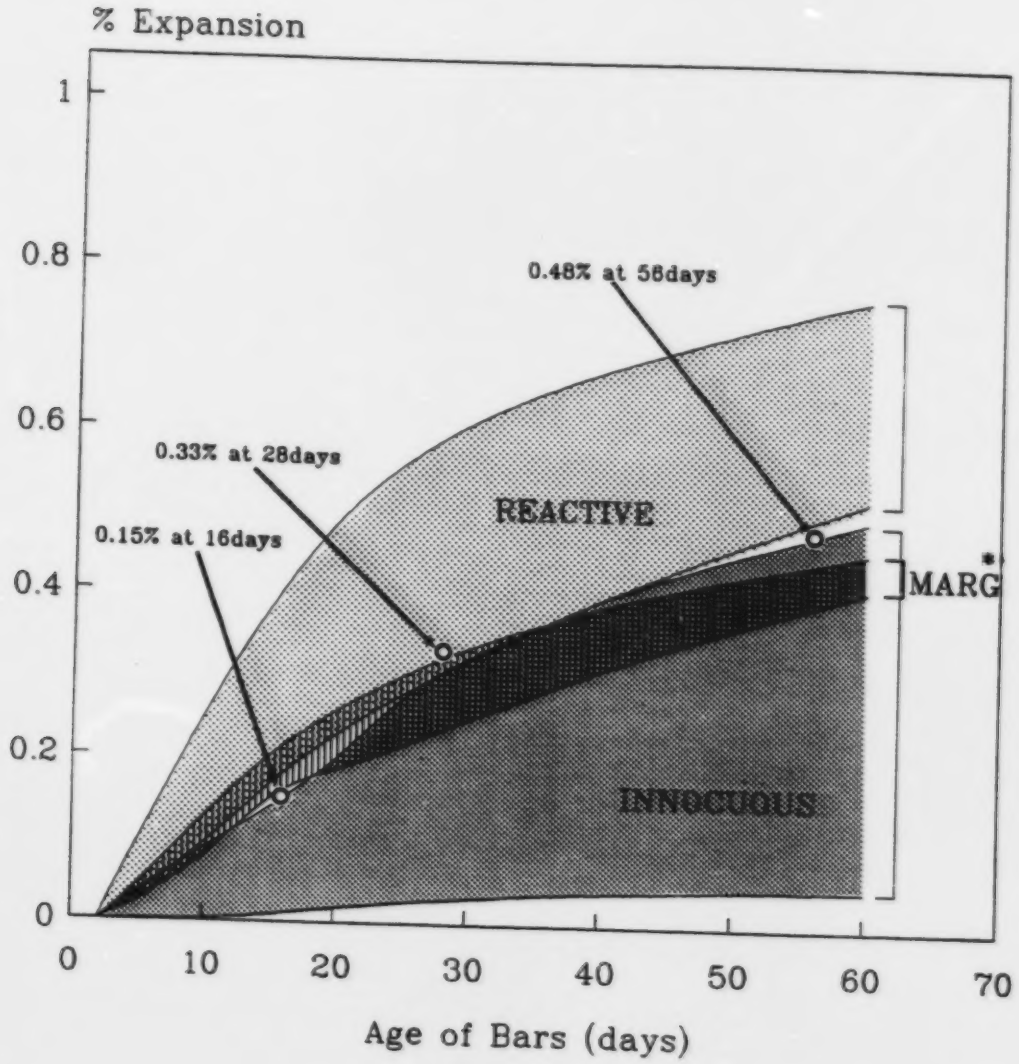
NBRI TEST – PHASE II
Reactive Aggregates



+ Expansion Limit
Note: 7 reactive aggregates plotted

FIG. 6

NBRI TEST – PHASE II
Reactivity Zones



+ Expansion Limit
* MARGINAL, but acceptable

Appendix A: Expansion Data for Concrete Prism Tests

NEW ALKALI PROJECT

OJTCRP PROJECT 87005

LAB. NUMBER	COURSE AGG.	FINE AGG.	28 D (MPa)	1 YR. (MPa)	*REMARKS	ALK. CONTENT
L-797/88	SPRATTS	GUELPH	41.78	57.46	-	1.25%
L-798/88	SUDBURY	GUELPH	35.29	50.50	GEL	1.25%
L-799/88	NELSON	GUELPH	39.45	55.63	-	1.25%
L-804/88	GRANT	GUELPH	34.93	49.76	GEL	1.25%
L-805/88	FLEMING	GUELPH	37.78	53.48	GEL	1.25%
L-809/88	PARIS	GUELPH	36.30	53.62	-	1.25%
L-810/88	NELSON	PARIS	43.69	66.94	GEL	1.25%
L-817/88	NELSON	NEYES	36.54	42.25	-	1.25%
L-818/88	NELSON	NATURAL	37.25	53.60	-	1.25%
L-819/88	MAPLE RIDGE	GUELPH	36.07	50.30	-	1.25%
L-825/88	McNULTY	GUELPH	34.67	44.46	-	1.25%
L-826/88	BEAUCEVILLE	GUELPH	40.39	49.55	GEL	1.25%
L-830/88	NELSON	NEYES	15.13	24.47	-	3.00%
L-831/88	NELSON	NATURAL	18.77	26.66	-	3.00%
L-838/88	MAPLE RIDGE	GUELPH	25.05	35.58	-	3.00%
L-839/88	McNULTY	GUELPH	24.99	32.15	-	3.00%
L-840/88	BEAUCEVILLE	GUELPH	22.57	29.38	-	3.00%
L-864/88	HUDSON N.Y.	GUELPH	43.49	55.86	-	1.25%
L-865/88	HUDSON N.Y.	GUELPH	23.32	25.92	CRACKING	3.00%
L-741/89	SPRINGHILL	GUELPH	36.47	47.10	-	1.25%
L-742/89	SPRINGHILL	GUELPH	20.77	25.31	-	3.00%
L-743/89	LOWER NOTCH	GUELPH	33.60	46.52	-	1.25%
L-744/89	LOWER NOTCH	GUELPH	21.80	30.53	-	3.00%
L-745/89	ADAMS MINE	GUELPH	20.76	27.92	-	3.00%
L-746/89	ADAMS MINE	GUELPH	30.37	38.70	-	1.25%

* REMARKS - INDICATE WHETHER CRACKING OR GEL.

LABORATORY TEST	SAMPLE DATA			
	87-40035 GUELPH	87-40067 PARIS	87-40085 NEYES	87-40102 NATURAL
Absorption, percent	0.81	1.01	0.95	0.90
Bulk Relative Density	2.689	2.675	2.643	2.642
Magnesium Sulphate Soundness, loss in percent	9.2	13.9	8.0	8.6
Attrition Loss, percent,	5.5	5.1	6.1	2.6
Fineness Modulus	2.65	2.74	3.93	2.77
Pass 75 um, percent	4.2	2.8	1.6	0.8
Organic	1	1	2	1
Chert (percent)	0.3	0.2	2.5	7.4

TABLE 2: FINE AGGREGATE PHYSICAL TEST DATA

LABORATORY TEST	SAMPLE DATA					
	SPRATT	SUDBURY	NELSON	87-40842 FLEMING	87-40851 GRANT	87-40866 PARIS
Petrographic Number (H.L.)	111	117	162	119	166	137
Absorption, percent	0.46	0.46	0.37	0.38	0.49	1.17
Bulk Relative Density	2.682	2.710	2.690	2.667	2.784	2.657
Magnesium Sulphate Soundness, loss in percent	1	1	2	3	1	2
Los Angeles Abrasion, loss in percent	18	13	28	49	13	22
Petrographic Composition (percent)						
Pontentially Reactive Components						
Chert	1.0					1.6
Sandstone		32		100%	9.5	
Argillite/Greywacke		32		Strained	17.2	
Quartzite		11		Granite	0.5	
Non-Reactive Components	99 Limestone	25 Gabbro	100 Dolostone		73 Granite and Diorite	98 Carbonates etc

TABLE 3: COARSE AGGREGATE PHYSICAL TEST DATA AND COMPOSITION

LABORATORY TEST	SAMPLE DATA			
	87-40032 MAPLE RIDGE	87-40052 LOWER NOTCH	87-40082 McNulty	87-40098 BEAUCEVILLE
Petrographic Number (H.L.)	100	101	108	100
Absorption, percent	0.50		0.50	0.30
Bulk Relative Density	2.740		2.707	2.709
Los Angeles Abrasion, loss in percent	14			9
Petrographic Composition (percent)				
Pontentially Reactive Components				
Chert	0	0	3	100
Sandstone/Arkose	19	28	12	Rhyolitic
Argillite/Greywacke	28	70	10	Tuff
Quartzite	4	0	2	
Non-Reactive Components	49 Granite, Diorite and Volcanic	2 Granite	73 Volcanic, Granite and Diorite	

TABLE 3: COARSE AGGREGATE PHYSICAL TEST DATA AND COMPOSITION

COARSE AGGREGATE:	LAB.# 797-88 SPRATTS (FROM STOCK)			COARSE AGGREGATE:	LAB.# 778-87 SPRATTS (FROM STOCK)		
FINE AGGREGATE:	GUELPH (87-88)			FINE AGGREGATE:	GUELPH (87-88)		
CEMENT TYPE:	ONT. HYDRO (391-88)			CEMENT TYPE:	CCL. BATH(345)		
411Kg WITH 1.25% EQUIV.ALKALIES				309Kg. WITH 3.0% EQUIV. ALKALIES			
W/C= 0.43				W/C= 0.53			
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.005	0.010	0.005	28	0.009	0.010	0.025
56	0.009	0.011	0.018	56	0.012	0.012	0.051
84	0.013	0.015	0.039	84	0.015	0.016	0.085
112	0.014	0.015	0.061	112	0.019	0.023	0.113
168	0.018	0.017	0.091	168	0.029	0.044	0.144
275	0.036*	0.031	0.116	275	0.060	0.098	0.179
364	0.062*	0.056	0.134	364	0.085*	0.133*	0.193*
546	0.087	0.099	0.143	546	0.124	0.170	0.205
728	0.094	0.129	0.150	728	0.128	0.175	0.213
910				910			
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1885	1930	1905	14			
84	1850	1835	1860	84			
168	1830	1825	1805	168			
275	1770	1820	1805	275			
364	1790	1820	1820	364			
546	1845	1860	1874	546			
728	1865	1885	1890	728			
910				910			
1092				1092			

NOTES:* CRACKING

	LAB.# 798-88				LAB.# 780-87		
COARSE AGGREGATE:	*SUDBURY (---)*			COARSE AGGREGATE:	*SUDBURY (---)*		
FINE AGGREGATE:	*GUELPH (87-88)*			FINE AGGREGATE:	*GUELPH (87-88)*		
CEMENT TYPE:	ONT. HYDRO (391-88)			CEMENT TYPE:	CCL BATH(#345)		
415Kg WITH 1.25% EQUIV.ALKALIES				312Kg. WITH 3.0% EQUIV. ALKALIES			
W/C= 0.44				W/C= 0.56			
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.002	0.009	0.005	28	0.008	0.008	0.005
56	0.006	0.014	0.007	56	0.010	0.011	0.011
84	0.009	0.016	0.010	84	0.007	0.009	0.020
112	0.008	0.016	0.011	112	0.009	0.009	0.036
168	0.007	0.016	0.013	168	0.012	0.011	0.088
275	0.006	0.018	0.011	275	0.012	0.016	0.151
364	0.012	0.021	0.021	364	0.019	0.021	0.174*
546	0.014	0.024	0.024	546	0.032	0.030	0.190
728	0.017	0.030	0.030	728	0.049*	0.037	0.200
910				910	0.064	0.041	0.201
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1865	1845	1845	14			
84	1920	1890	1885	84			
168	1895	1875	1870	168			
275	1890	1880	1880	275			
364	1900	1880	1885	364			
546	1900	1890	1890	546			
728	1905	1890	1890	728			
910				910			
1092				1092			

NOTES:* CRACKING

	LAB.# 804-88				LAB.# 800-85		
COARSE AGGREGATE:	*FLEMING (87-40042)*			COARSE AGGREGATE:	*FLEMING (84-40057)*		
FINE AGGREGATE:	*GUELPH (87-88)*			FINE AGGREGATE:	*GUELPH*		
CEMENT TYPE:	ONT. HYDRO (391-88)			CEMENT TYPE:	CCL BATH		
402Kg WITH 1.25% EQUIV.ALKALIES				310Kg. WITH 3.0% EQUIV. ALKALIES			
W/C=	0.43			W/C=	0.57		
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.008	0.012	0.008	28	N.D.	N.D.	0.001
56	0.013	0.015	0.010	56			0.005
84	0.013	0.016	0.013	84			0.008
112	0.015	0.019	0.013	112			0.013
168	0.018	0.022	0.017	168			0.026
275	0.014	0.019	0.015	275			---
364	0.023	0.024	0.022	364			0.077*
546	0.029	0.029	0.028	546			0.086
728	0.027	0.035	0.030	728			0.092
910				910			0.097
1092				1092			DISCONTINUED
1274				1274			DISCONTINUED
1456				1456			DISCONTINUED
1638				1638			DISCONTINUED
1820				1820			DISCONTINUED
	RESONANT FREQUENCY MOIST 38°C					RESONANT FREQUENCY MOIST 38°C	
AGE				AGE			
14	1765	1710	1775	14			
84	1821	1783	1855	84			
168	1840	1800	1865	168			
275	1845	1810	1870	275			
364	1860	1830	1890	364			
546	1870	1845	1900	546			
728	1880	1850	1920	728			
910				910			
1092				1092			

NOTES:* CRACKING N.D.= NO DATA

LAB.# 805-88				LAB.# 787-85			
COARSE AGGREGATE:	GRANT (87-40051)			COARSE AGGREGATE:	GRANT (84-40046)		
FINE AGGREGATE:	GUELPH (87-88)			FINE AGGREGATE:	GUELPH		
CEMENT TYPE:	ONT. HYDRO (391-88)			CEMENT TYPE:	CCL BATH		
415Kg WITH 1.25% EQUIV.ALKALIES				310Kg. WITH 3.0% EQUIV. ALKALIES			
W/C=	0.43			W/C=	0.63		
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.001	0.005	0.004	28	N.D.	N.D.	-0.001
56	0.004	0.007	0.009	56			0.002
84	0.005	0.007	0.010	84			0.001
112	0.006	0.011	0.012	112			0.002
168	0.009	0.013	0.014	168			0.042
275	0.005	0.010	0.008	275			---
364	0.008	0.014	0.017	364			0.138*
546	0.018	0.020	0.024	546			0.142
728	0.019	0.025	0.026	728			0.143
910				910			0.156
1092				1092			DISCONTINUED
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1880	1885	1865	14			
84	1930	1950	1925	84			
168	1940	1920	1935	168			
275	1950	1930	1935	275			
364	1960	1930	1950	364			
546	1900	1930	1945	546			
728	1970	1950	1960	728			
910				910			
1092				1092			

NOTES:* CRACKING N.D.= NO DATA

	LAB.# 809-88				LAB.#		
COARSE AGGREGATE:	*PARIS(87-4006)*			COARSE AGGREGATE:			
FINE AGGREGATE:	*GUELPH (87-88)*			FINE AGGREGATE:			
CEMENT TYPE:	ONT. HYDRO (391-88)			CEMENT TYPE:			
415Kg WITH 1.25% EQUIV.ALKALIES				310Kg. WITH 3.0% EQUIV. ALKALIES			
W/C=	0.46			W/C=			
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.007	0.011	0.005	28			
56	0.012	0.014	0.008	56			
84	0.013	0.015	0.005	84			
112	0.015	0.015	0.009	112			
168	0.014	0.016	0.010	168			
275	0.015	0.019	0.009	275			
364	0.017	0.025	0.015	364			
546	---	---	---	546			
728	0.021	0.027	0.019	728			
910				910			
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C					RESONANT FREQUENCY MOIST 38°C	
AGE				AGE			
14	1795	1780	1800	14			
84	1855	1840	1855	84			
168	1865	1855	1870	168			
275	1880	1865	1885	275			
364	1870	1870	1910	364			
546	1890	1860	1890	546			
728	1900	1880	1895	728			
910				910			
1092				1092			

NOTES:* CRACKING

	LAB.# 810-88			LAB.#			
COARSE AGGREGATE:	*NELSON (58-87)*			COARSE AGGREGATE:			
FINE AGGREGATE:	*PARIS (87-40067)*			FINE AGGREDATE:			
CEMENT TYPE:	ONT. HYDRO (391-88)			CEMENT TYPE:			
415Kg WITH 1.25% EQUIV.ALKALIES				310Kg. WITH 3.0% EQUIV. ALKALIES			
W/C=	0.47			W/C=			
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.007	0.007	0.007	28			
56	0.009	0.011	0.010	56			
84	0.010	0.011	0.007	84			
112	0.011	0.011	0.013	112			
168	0.011	0.012	0.013	168			
275	0.011	0.015	0.012	275			
364	0.015	0.020	0.018	364			
546	---	---	---	546			
728	0.017	0.023	0.020	728			
910				910			
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1880	1910	1885	14			
84	1935	1955	1935	84			
168	1945	1970	1935	168			
275	1965	1980	1960	275			
364	1955	1960	1985	364			
546	1955	1990	1965	546			
728	1960	1995	1965	728			
910				910			
1092				1092			

NOTES:* CRACKING

COARSE AGGREGATE:	LAB.# 817-88 *NELSON(58-87)*			COARSE AGGREGATE:	LAB.# 830-88 *NELSON (58-87)*		
FINE AGGREGATE:	*NEYES(87-40085)*			FINE AGGREGATE:	*NEYES (87-40085)*		
CEMENT TYPE:	ONT. HYDRO (391-88)			CEMENT TYPE:	C.C.L.BATH (386-87)		
400Kg WITH 1.25% EQUIV.ALKALIES				297Kg. WITH 3.0% EQUIV. ALKALIES			
W/C= 0.47				W/C= 0.59			
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.003	0.008	-0.001	28	0.005	0.006	0.003
56	0.009	0.012	0.004	56	0.005	0.007	0.010
84	0.007	0.012	0.002	84	0.005	0.010	-0.001
112	0.008	0.015	0.003	112	0.004	0.011	-0.001
168	0.008	0.017	0.002	168	0.006	0.012	0.005
275	0.010	0.021	0.002	275	0.004	0.013	0.003
364	0.016	0.024	0.004	364	0.010	0.017	0.013
546	0.014	0.030	0.006	546	0.005	0.016	0.020
728	0.015	0.031	0.008	728	0.008	0.021	0.022
910				910			
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1750	1765	1780	14	1765	1655	1680
84	1810	1825	1840	84	1645	1660	1660
168	1830	1840	1855	168	1650	1675	1670
275	1845	1855	1865	275	1660	1685	1675
364	1845	1845	1870	364	1675	1700	1690
546	1855	1860	1880	546	1670	1685	1690
728	1865	1865	1880	728	1680	1690	1690
910				910			
1092				1092			

NOTES:* CRACKING

LAB.# 818-88				LAB.# 831-88			
COARSE AGGREGATE: NELSON(58-87)				COARSE AGGREGATE: NELSON (58-87)			
FINE AGGREGATE: NATURAL (87-40102)				FINE AGGREGATE: NATURAL (87-40102)			
CEMENT TYPE: ONT. HYDRO (391-88)				CEMENT TYPE: C.C.L.BATH (386-87)			
402Kg WITH 1.25% EQUIV.ALKALIES				303Kg. WITH 3.0% EQUIV. ALKALIES			
W/C= 0.46				W/C= 0.59			
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.007	0.009	0.006	28	0.006	0.005	0.006
56	0.012	0.015	0.011	56	0.009	0.005	0.010
84	0.011	0.012	0.009	84	0.008	0.007	0.014
112	0.011	0.015	0.013	112	0.007	0.008	0.019
168	0.010	0.017	0.011	168	0.013	0.009	0.033
275	0.012	0.020	0.015	275	0.011	0.011	0.049
364	0.015	0.025	0.018	364	0.015	0.014	0.059
546	0.017	0.030	0.016	546	0.011	0.012	0.056
728	0.020	0.030	0.021	728	0.014	0.018	0.060
910				910			
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1830	1810	1830	14	1595	1615	1620
84	1880	1865	1875	84	1800	1680	1710
168	1895	1875	1895	168	1815	1665	1720
275	1915	1890	1890	275	1820	1660	1720
364	1905	1885	1910	364	1830	1680	1730
546	1915	1905	1915	546	1840	1700	1745
728	1915	1905	1925	728	1850	1715	1750
910				910			
1092				1092			

NOTES:* CRACKING

LAB.# 819-88	LAB.# 838-88
COARSE AGGREGATE: *MAPLE RIDGE(87-40032)*	COARSE AGGREGATE: *MAPLE RIDGE (87-40032)*
FINE AGGREGATE: *GUELPH (87-88)*	FINE AGGREGATE: *GUELPH (87-88)*
CEMENT TYPE: ONT. HYDRO (391-88)	CEMENT TYPE: C.C.L. BATH(386-87)
401Kg WITH 1.25% EQUIV.ALKALIES	301Kg. WITH 3.0% EQUIV. ALKALIES
W/C= 0.43	W/C= 0.60

AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.006	0.007	0.004	28	0.006	0.007	0.003
56	0.010	0.011	0.009	56	0.010	0.007	0.005
84	0.008	0.011	0.008	84	0.008	0.010	0.008
112	0.009	0.013	0.010	112	0.012	0.013	0.012
168	0.009	0.014	0.009	168	0.010	0.008	0.012
275	0.010	0.017	0.018	275	0.009	0.012	0.021
364	0.014	0.020	0.020	364	0.013	0.016	0.040
546	0.014	0.025	0.022	546	0.019	0.021	0.069
728	0.016	0.026	0.027	728	0.027	0.027	0.084
910				910			
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			

	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1810	1800	1810	14	1830	1815	1795
84	1865	1855	1865	84	1860	1850	1865
168	1875	1870	1875	168	1870	1870	1850
275	1890	1880	1890	275	1870	1860	1870
364	1890	1875	1890	364	1855	1840	1845
546	1890	1860	1895	546	1840	1830	1865
728	1895	1895	1915	728	1850	1830	1775
910				910			
1092				1092			

NOTES:* CRACKING

	LAB.# 825-88				LAB.# 839-88		
COARSE AGGREGATE:	McNULTY(87-40082)			COARSE AGGREGATE:	McNULTY(87-40082)		
FINE AGGREGATE:	GUELPH(87-88)			FINE AGGREGATE:	GUELPH(87-88)		
CEMENT TYPE:	ONT.HYDRO (391-88)			CEMENT TYPE:	C.C.L.BATH(386-87)		
400Kg WITH 1.25% EQUIV.ALKALIES				306Kg. WITH 3.0% EQUIV. ALKALIES			
W/C= 0.43				W/C= 0.56			
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.006	0.009	0.007	28	0.005	0.008	0.004
56	0.009	0.012	0.011	56	0.010	0.009	0.011
84	0.009	0.012	0.012	84	0.007	0.012	0.016
112	0.008	0.012	0.012	112	0.010	0.015	0.025
168	0.012	0.016	0.016	168	0.011	0.015	0.035
275	0.010	0.017	0.022	275	0.012	0.017	0.099*
364	0.018	0.022	0.030	364	0.019	0.024	0.129*
546	0.018	0.025	0.035	546	0.033	0.041	0.148
728	0.022	0.028	0.035	728	0.052	0.062	0.159
910				910			
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1785	1800	1755	14	1775	1785	1785
84	1840	1850	1810	84	1810	1820	1820
168	1840	1850	1810	168	1810	1800	1815
275	1845	1860	1815	275	1740	1720	1750
364	1845	1855	1825	364	1725	1695	1720
546	1860	1817	1830	546	1745	1730	1750
728	1865	1875	1835	728	1755	1750	1770
910				910			
1092				1092			

*NOTES CRACKING

COARSE AGGREGATE:	LAB.# 826-88 BEAUCEVILLE(87-40098)			COARSE AGGREGATE:	LAB.# 840-88 BEAUCEVILLE(87-40098)		
FINE AGGREGATE:	GUELPH(87-88)			FINE AGGREGATE:	GUELPH(87-88)		
CEMENT TYPE:	ONT.HYDRO (391-88)			CEMENT TYPE:	C.C.L. BATH(386-87)		
403Kg WITH 1.25% EQUIV.ALKALIES				309Kg. WITH 3.0% EQUIV. ALKALIES			
W/C= 0.43				W/C= 0.54			
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.005	0.007	0.005	28	0.006	0.012	0.018
56	0.010	0.011	0.014	56	0.013	0.015	0.037
84	0.010	0.013	0.026	84	0.016	0.021	0.055
112	0.010	0.014	0.088	112	0.025	0.028	0.077
168	0.016	0.020	0.088	168	0.037	0.037	0.119*
275	0.021	0.028	0.128*	275	0.079*	0.077*	0.172*
364	0.037*	0.040	0.142*	364	0.134*	0.150*	0.188*
546	0.056	0.067	0.147	546	0.191	0.240	0.195
728	0.063	0.094	0.219	728	0.020	0.292	0.202
910				910			
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1750	1755	1760	14	1770	1775	1775
84	1750	1755	1760	84	1710	1725	1710
168	1750	1755	1755	168	1660	1675	1670
275	1755	1725	1755	275	1640	1650	1610
364	1785	1760	1780	364	1640	1650	1635
546	1800	1795	1805	546	1670	1690	1690
728	1815	1805	1815	728	1700	1710	1700
910				910			
1092				1092			

*NOTES CRACKING

	LAB.# 864-88		
COARSE AGGREGATE:	*HUDSON N. Y. (88-B-40021)*		
FINE AGGREGATE:	*GUELPH (87-88)*		
CEMENT TYPE:	C.C.L.BATH (386-87)		
408Kg WITH 1.25% EQUIV.ALKALIES			
W/C=	0.43		

AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	-0.001	0.005	-0.011
56	0.000	0.009	0.003
84	-0.003	0.006	-0.002
112	0.001	0.010	0.004
168	0.001	0.010	0.004
275	0.003	0.015	0.010
364	0.005	0.020	0.010
546	0.005	0.022	0.012
728	0.011	0.027	0.012
910			
1092			
1274			
1456			
1638			
1820			

	RESONANT FREQUENCY MOIST 38°C		
AGE			
14	1845	1825	1820
84	1890	1880	1870
168	1905	1895	1880
275	1910	1905	1895
364	1915	1905	1895
546	1925	1920	1900
728	1930	1920	1905
910			
1092			

	LAB.# 865-88		
COARSE AGGREGATE:	*HUDSON N.Y.(88-B-40021)*		
FINE AGGREGATE:	*GUELPH (87-88)*		
CEMENT TYPE:	C.C.L.BATH (386-87)		
307Kg. WITH 3.0% EQUIV. ALKALIES			
W/C=	0.60		

AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.001	0.003	0.010
56	0.005	0.007	0.031
84	0.004	0.005	0.059
112	0.010	0.012	0.095*
168	0.023*	0.018	0.015*
275	0.066*	0.076	0.201*
364	0.104*	0.120*	0.209*
546	0.135	0.179	0.215
728	0.143	0.214	0.217
910			
1092			
1274			
1456			
1638			
1820			

	RESONANT FREQUENCY MOIST 38°C		
AGE			
14	1750	1750	1765
84	1725	1725	1735
168	1745	1720	1745
275	1660	1630	1655
364	1670	1650	1675
546	1705	1680	1710
728	1720	1700	1735
910			
1092			

NOTES:* CRACKING

COARSE AGGREGATE:	LAB.# 741-89 SPRINGHILL (88-B-40052)			COARSE AGGREGATE:	LAB.# 742-89 SPRINGHILL (88-B-40052)		
FINE AGGREGATE:	GUELPH (88-89)			FINE AGGREGATE:	GUELPH (88-89)		
CEMENT TYPE:	ONT. HYDRO (406-89)			CEMENT TYPE:	C.C.L. BATH (405-89)		
408Kg WITH 1.25% EQUIV.ALKALIES				306Kg. WITH 3.0% EQUIV. ALKALIES			
W/C= 0.45				W/C= 0.60			
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.004	0.009	0.013	28	0.007	0.008	0.016
56	0.005	0.013	0.018	56	0.008	0.011	0.052
84	0.004	0.013	0.023	84	0.009	0.013	0.102
112	0.002	0.012	0.027	112	0.008	0.020	0.130
168	0.001	0.011	0.053	168	0.014	0.025	0.157
275	0.013	0.019	0.097	275	0.057	0.082	0.206
364	0.016	0.021	0.105	364	0.078	0.113	0.209
546				546			
728				728			
910				910			
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1805	1790	1825	14	1715	1725	1735
84	1885	1830	1870	84	1650	1665	1670
168	1785	1805	1830	168	1630	1650	1665
275	1745	1775	1815	275	1640	1650	1665
364	1820	1805	1820	364	1710	1660	1660
546				546			
728				728			
910				910			
1092				1092			

NOTES:* CRACKING

	LAB.#	743-89
COARSE AGGREGATE:	LOWER NOTCH	(88-B-40064)
FINE AGGREGATE:	GUELPH	(88-89)
CEMENT TYPE:	ONT. HYDRO	(406-89)
408Kg WITH 1.25% EQUIV.ALKALIES		
W/C=	0.44	

AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.005	0.013	0.010
56	0.006	0.017	0.012
84	0.005	0.016	0.015
112	0.001	0.015	0.024
168	0.000	0.015	0.019
275	0.010	0.024	0.039*
364	0.012	0.026	0.047*
546			
728			
910			
1092			
1274			
1456			
1638			
1820			

	RESONANT FREQUENCY MOIST 38°C		
AGE			
14	1850	1805	1825
84	1900	1860	1895
168	1905	1865	1900
275	1905	1865	1895
364	1905	1860	1890
546			
728			
910			
1092			

	LAB.#	744-89
COARSE AGGREGATE:	LOWER NOTCH	(88-B-40064)
FINE AGGREGATE:	GUELPH (88-89)	
CEMENT TYPE:	C.C.L. BATH	(405-89)
307Kg. WITH 3.0% EQUIV. ALKALIES		
W/C=	0.59	

AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.001	0.003	0.006
56	0.006	0.007	0.012
84	0.006	0.007	0.014
112	0.004	0.004	0.020
168	0.000	0.003	0.030
275	0.013	0.014	0.100*
364	0.015	0.018	0.123*
546			
728			
910			
1092			
1274			
1456			
1638			
1820			

	RESONANT FREQUENCY MOIST 38°C		
AGE			
14	1785	1780	1765
84	1820	1815	1790
168	1800	1795	1785
275	1745	1760	1740
364	1750	1760	1740
546			
728			
910			
1092			

NOTES:* CRACKING

COARSE AGGREGATE:	LAB.# 746-89 *ADAMS MINE (88-B-40065)*			COARSE AGGREGATE:	LAB.# 745-89 *ADAMS MINE (88-B-40065)*		
FINE AGGREGATE:	*GUELPH (88-89)*			FINE AGGREGATE:	*GUELPH (88-89)*		
CEMENT TYPE:	ONT. HYDRO (406-89)			CEMENT TYPE:	C.C.L. BATH (405-89)		
401Kg WITH 1.25% EQUIV.ALKALIES				305Kg. WITH 3.0% EQUIV. ALKALIES			
W/C= 0.44				W/C= 0.60			
AGE:	STORAGE CONDITIONS :			AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C		MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.004	0.000	0.011	28	-0.001	0.001	0.010
56	0.009	0.003	0.018	56	0.004	0.006	0.022
84	0.011	0.004	0.020	84	0.006	0.005	0.028
112	0.011	0.002	0.023	112	0.004	0.005	0.038
168	0.008	0.004	0.036	168	0.003	0.006	0.058
275	0.020	0.016	0.071	275	0.019	0.021	0.110
364	0.023	0.022	0.083	364	0.026	0.030	0.128
546				546			
728				728			
910				910			
1092				1092			
1274				1274			
1456				1456			
1638				1638			
1820				1820			
	RESONANT FREQUENCY MOIST 38°C				RESONANT FREQUENCY MOIST 38°C		
AGE				AGE			
14	1755	1740	1740	14	1760	1750	1725
84	1770	1755	1755	84	1730	1755	1715
168	1740	1730	1740	168	1690	1705	1660
275	1710	1745	1695	275	1640	1660	1615
364	1700	1720	1760	364	1640	1640	1650
546				546			
728				728			
910				910			
1092				1092			

NOTES:* CRACKING

LAB.# 799-88			
COARSE AGGREGATE:	*NELSON(58-87)*		
FINE AGGREGATE:	*GUELPH (87-88)*		
CEMENT TYPE:	ONT. HYDRO (391-88)		
399Kg WITH 1.25% EQUIV.ALKALIES			
W/C= 0.46			

AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.003	0.007	0.007
56	0.010	0.012	0.009
84	0.013	0.015	0.011
112	0.011	0.014	0.010
168	0.010	0.015	0.011
275	0.010	0.016	0.008
364	0.015	0.019	0.015
546	0.016	0.022	0.018
728	0.021	0.026	0.018
910			
1092			
1274			
1456			
1638			
1820			

	RESONANT FREQUENCY MOIST 38°C		
AGE			
14	1850	1850	1860
84	1875	1875	1885
168	1890	1890	1900
275	1890	1900	1910
364	1900	1900	1910
546	1900	1910	1915
728	1905	1910	1920
910			
1092			

LAB.# 786-87			
COARSE AGGREGATE:	*NELSON(58-87)*		
FINE AGGREGATE:	*GUELPH (87-88)*		
CEMENT TYPE:	CCL BATH(#345)		
308Kg. WITH 3.0% EQUIV. ALKALIES			
W/C= 0.56			

AGE:	STORAGE CONDITIONS :		
	MOIST. 23°C	NaCL 23°C	MOIST@38°C
28	0.007	0.008	0.012
56	0.007	0.010	0.004
84	0.008	0.008	0.013
112	0.010	0.011	0.013
168	0.013	0.015	0.023
275	0.013	0.015	0.022
364	0.021	0.020	0.027
546	0.022	0.023	0.033
728	0.028	0.027	0.034
910	0.033	0.034	0.039
1092	0.028	0.032	0.036
1274			
1456			
1638			
1820			

	RESONANT FREQUENCY MOIST 38°C		
AGE			
14			
84			
168			
275			
364			
546			
728			
910			
1092			

NOTES:* CRACKING

Appendix B: CSA Draft Method for NBRI Mortar Bar Test

R.D. HOOTON AND C. ROGERS
DRAFT #3: January 25, 1990

CSA CAN3-A23.2-XXC

Standard Test Method for Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction

1. Scope:

1.1 This test method is for detecting within 16 days the potential for deleterious expansion of mortar bars due to the alkali-silica and slow/late-expanding alkali silicate/silica reactions.

1.2 Alkalies participating in the expansive reactions usually are derived from the cement; under some circumstances they may be derived from other constituents of the concrete or from external sources. Three types of alkali reactivity of aggregates are recognized: (1) an alkali-silica reaction involving certain siliceous rocks, minerals, and natural or artificial glasses (see CAN3-A23.1, Appendix B2.2), (2) a slow/late-expanding alkali-silicate/silica reaction (see CAN3-A23.1, Appendix B2.3), and (3) an alkali-carbonate reaction involving dolomite in certain calcitic dolostones and dolomitic limestones. The method is not recommended as a means to detect the latter reaction because expansions produced in the mortar-bar test by the alkali-carbonate reaction are generally much less than those produced by the alkali-silica reaction for combinations having equally harmful effects in service. The concrete prism expansion test (CAN3-A23.2-14A) is the only satisfactory method of determining expansivity of alkali-carbonate reactive aggregates.

1.3 This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. A specific precautionary statement is given in 5.3.1.

2. Referenced Documents:

2.1	CSA Standards:	CAN3-A5-M88	Portland Cements
		CAN3-A23.2-14A	Alkali-aggregate Reaction
		CAN3-A23.1-M77	Appendix B (Supplement No. 2 - 1986)
2.2	CSGB Standards:	8-GP-2M	Sieves, Testing, Woven Wire, Metric
2.3	ASTM Standards:	C 227	Test Method for Potential Alkali Reactivity of Cement - Aggregate Combinations (Mortar Bar Method)
		C 490	Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete.

3. **Significance and Use:**

3.1 This test method provides a means of detecting the potential of an aggregate used in concrete for undergoing alkali-silica or slow/late-expanding alkali silicate/silica reactions and consequent potentially deleterious expansion. It is based on the NBRI Accelerated Test Method[1,2,3]. It provides an alternative method to ASTM C 227 and may be especially useful for aggregates that react slowly or produce expansion late in the reaction.

Note 1 - Because the specimens are exposed to a NaOH solution, the alkali content of the cement is not a significant factor in affecting expansions. However, the method has been found to be suitable for determining the ability of a supplementary cementing material to control the expansion[2]. However, further research is required before this test is recommended for evaluating supplementary cementing materials.

3.2 When expansions greater than 0.10% are developed within 16 days from casting, it is strongly recommended that supplementary information be developed to confirm that the expansion is actually due to alkali reactivity (see Appendix B of CAN3-A23.1).

3.3 When it has been concluded from the results of tests performed using this method and supplementary information that a given aggregate should be considered potentially deleteriously reactive, additional studies possibly using alternate test methods, may be appropriate to develop information on the potential reactivity of other combinations containing the same cement with other aggregates, or the same cement-aggregate combination with supplementary cementing materials.

4. **Apparatus:**

4.1 The apparatus shall conform to ASTM Specification C 490, except as follows:

4.2 *Sieves* - Square hole, woven-wire cloth sieves, shall conform to CGSB Standard 8-GP-2M.

4.3 *Mixer, Paddle, and Mixing Bowl* - Mixer, paddle, and mixing bowl shall conform to the requirements of CAN3-A5-M88, Section 8.4.5, except that the clearance between the lower end of the paddle and the bottom of the bowl shall be 5.1 ± 0.3 mm.

4.4 *Tamper and Trowel* - The tamper and trowel shall conform to CAN3-A5-M88 Sections 8.4.8 and 8.4.9.

4.5 *Containers* - The containers must be of such a nature that the bars can be totally immersed in either the water or 1N NaOH solution. The containers must be made of material that can withstand prolonged exposure to 80°C and must be inert to a 1N NaOH solution. The containers must be so constructed that when used for storing specimens the loss of moisture is prevented by tight-fitting covers or by sealing or by - both. The bars in the solution must be placed and supported so that the solution has access to the whole of the bar; therefore, it should be ensured that the specimens do not touch the sides of the container or each other. The specimens, if stood upright in the solution, cannot be supported by the metal gauge stud.

Note 2 - The caustic NaOH solution will corrode glass or metal containers.

Note 3 - A covered container that has been found to be acceptable for this purpose is sold by Rubbermaid as a microwave-proof food storage container.

4.6 *Oven* - A convection oven with temperature control maintaining 80° ± 2°C.

5. **Reagents:**

5.1 *Sodium Hydroxide (NaOH)* - USP or technical grade may be used, provided it is established that it is of sufficiently high purity to permit its use without lessening the accuracy of the determination. When tests are made that are expected to produce results that are close to an acceptance-rejection value, it is recommended that reagent grade chemicals be used.

5.2 *Purity of Water* - Unless otherwise indicated, references to water shall be understood to mean distilled water.

5.3 *Sodium Hydroxide Solution* - Each litre of solution shall contain 40.0 g of NaOH dissolved in 900 ml of water, and shall be diluted with additional distilled or deionized water to obtain 1.0L of solution. The volume proportion of sodium hydroxide solution to mortar bars in a storage container shall be 4 ± 0.5 volumes of solution to 1 volume of mortar bars.

Note 4 - The volume of a mortar bar may be taken as 184 mL.

5.3.1 *Precaution* - Before using NaOH review (1) the safety precautions for using NaOH, (2) first aid for burns, and (3) the emergency response to spills, as described in the manufacturer's Material Safety Data Sheet or other reliable safety literature. NaOH can cause very severe burns and injury to unprotected skin and eyes. Suitable personal protective equipment should always be used. These should include full-face shields, rubber aprons, and gloves impervious to NaOH. Gloves should be checked periodically for pin holes.

6. **Temperature and Humidity:**

6.1 The temperature of the molding room and dry materials shall be maintained at not less than 20°C and not more than 27.5°C. The temperature of the mixing water and of the moist closet or moist room shall not vary from 23°C by more than 2°C.

6.2 The relative humidity of the molding room shall be not less than 50%. The moist closet or room shall conform to CAN3-A5-M83, Clause 8.3.2.

6.3 The storage oven in which the specimens are stored in the containers shall be maintained at a temperature that shall not vary from 80°C by more than 2°C.

7. **Selection and Preparation of Materials:**

7.1 *Selection of Aggregate* - Materials proposed for use as fine aggregate in concrete shall be processed as described in 7.2 with a minimum of crushing. Materials proposed for use as coarse aggregate in concrete shall be processed by crushing to produce as nearly as practical a graded product from which a sample can be obtained. The sample shall have the grading as prescribed in 7.2 and be representative of the composition of the coarse aggregate as proposed for use.

7.1.1 When a given quarried material is proposed for use, both as coarse and as fine aggregate, it will be tested only by selection of an appropriate sample crushed to the fine aggregate sizes, unless there is reason to expect that the coarser size fractions have a different composition than the finer sizes and that these differences might significantly affect expansion due to reaction with the alkalies in cement. In this case the coarser size fractions should be tested in a manner similar to that employed in testing the fine aggregate sizes.

7.1.2 Coarse aggregate crushed to sand size may give increased expansion, owing to the increased surface exposed upon crushing. Therefore, if coarse aggregate tested by this method produces an excessive amount of expansion, the material shall not be classed as objectionably reactive with alkali unless tests of concrete specimens confirm the findings of the tests of the mortar.

7.2 *Preparation of Aggregate* - All aggregates to which this method is applied shall be graded in accordance with the requirements prescribed in Table 1. Aggregates in which sufficient quantities of the sizes specified in Table 1 do not exist shall be crushed until the required material has been produced. In the case of aggregates containing insufficient amounts of one or more of the larger sizes listed in Table 1, and if no larger material is available for crushing, the first size in which sufficient material is available shall contain the cumulative percentage of material down to that size as determined from the grading specified in Table 1. When such procedures are required, special note shall be made thereof in the test report. After the aggregate has been separated into the various sieve sizes, each size shall be washed with a water spray over the sieve to remove adhering dust and fine particles from the aggregate. (Note 5). The portions retained on the various sieves shall then be dried and, unless used immediately, each such portion shall be stored individually in a clean container provided with a tight-fitting cover.

TABLE 1: GRADING REQUIREMENTS

Sieve Size				Mass %
Passing		**Retained on**		
5	mm	2.5	mm	10
2.5	mm	1.25	mm	25
1.25	mm	630	µm	25
630	µm	315	µm	25
315	µm	160	µm	15

Note 5 - Tests have shown that mortar bar expansions obtained in this method are less susceptible than in ASTM Method C 227 to variability if the aggregates are not washed.

7.3 ***Selection and Preparation of Cement:***

7.3.1 *Reference Cement* - The portland cement used shall meet the requirements of CAN3-A5-M83.

Note 6 - Since the bars are immersed in NaOH solution, the alkali content of the cement has a negligible influence on expansion.

7.3.2 *Preparation of Cement* - Cement for use in this test shall be passed through a 1.25 mm sieve to remove lumps before use.

8. Preparation of Test Specimens:

8.1 *Number of Specimens* - Make at least three test specimens for each cement-aggregate combination.

8.2 *Preparation of Molds* - Prepare the specimen molds in accordance with the requirements of ASTM Specification C 490 except, the interior surfaces of the mold shall be covered with a release agent. A release agent will be acceptable if it serves as a parting agent without affecting the setting of the cement and without leaving any residue that will inhibit the penetration of water into the specimen.

Note 7 - TFE-fluorocarbon tape complies with the requirements for a mold release agent.

8.3 *Proportioning of Mortar* - Proportion the dry materials for the test mortar using 1 part of cement to 2.25 parts of graded aggregate by mass. The quantities of dry materials to be mixed at one time in the batch of mortar for making three specimens shall be 440g of cement and 990g of aggregate made up by re-combining the portions retained on the various sieves (see 7.2) in the grading prescribed in Table 1. For natural fine aggregates, use a water to cement ratio equal to 0.44 by mass. For coarse aggregates or manufactured sands, use a water to cement ratio equal to 0.50 by mass.

Note 8 - Ruggedness tests indicated that mortar bar expansions were less variable at a fixed water to cement ratio than when gauged to a constant flow.[3] The water to cement ratios selected should give acceptable workability in most cases.[4]

8.4 *Mixing of Mortar* - Mix the mortar in accordance with the requirements of Method CAN3-A5-M88, Section 7.5.

8.5 *Molding of Test Specimens* - Start molding specimens with a total elapsed time of not more than 2 min and 15 s after completion of the original mixing of the mortar batch. Fill the molds with two approximately equal layers, each layer being compacted with the tamper. Work the mortar into the corners, around the gauge studs, and along the surfaces of the mold with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, cut off the mortar flush with the top of the mold and smooth the surface with two strokes of the trowel.

9. **Storage and Measurement of Test Specimens**

9.1 *Initial Storage and Measurement* - After each mold has been filled, place the mold immediately in the moist cabinet or room. The specimens shall remain in the molds for 24 ± 2 h. Then remove them from the molds and, while being protected from loss of moisture, properly identify. The initial and all subsequent measurements shall be made and recorded to the nearest 0.002 mm. Place the specimens of each aggregate sample in a storage container with sufficient tap water to totally immerse them. Seal and place the containers in an oven or room at 80°C ± 2°C for a period of 24 hours.

9.2 *Zero Measurements* - For the zero measurement of the specimens, the containers shall be removed from the oven one at a time. Other containers are only removed once the bars in the first container have been measured and returned to the oven. Remove the bars one at a time from the water and dry their surface with a towel paying particular attention to the two metal gauge measuring studs. The zero measurement of each prism is done immediately after drying and the reading is taken as soon as the bar is in position. The process of drying and measuring is to be completed within 15 ± 5 seconds of removing the specimen from the water. After measurement, the specimen is left on a towel until the remainder of the bars have been measured, after which they are all placed in a separate container with sufficient 1N NaOH, at 80° ± 2°C for the samples to be totally immersed. The container is then sealed and returned to the oven and the process repeated for the remaining containers.

Note 9 - The comparator bar should be measured prior to each set of specimens since the heat from the mortar bars may cause the length of the comparator to change.

9.3 *Subsequent storage and measurement.* Subsequent measurement of the specimens is undertaken periodically, with at least three intermediate readings, for 14 days after the zero reading, at approximately the same time each day. The measuring procedure is identical to that described in 9.2 except that the specimens are returned to their own container after measurement.

10. **Calculation:**

10.1 Calculate the difference between the zero length of the specimen and the length at each period of measurement to the nearest 0.001 per cent of the effective gauge length and record as the expansion of the specimen for that period. Report the average expansion of the four specimens of a given cement-aggregate combination to the nearest 0.01 per cent as the expansion for the combination for a given period.

11. **Report:**

11.1 The report shall include the following:

11.1.1 Type and source of aggregate,

11.1.2 Type and source of portland cement,

11.1.3 Alkali content of cement as percent potassium oxide (K_2O), sodium oxide (Na_2O), and calculated sodium oxide (Na_2O) equivalent,

11.1.4 Average length change in percent at each reading of the specimens.

11.1.5 Any relevant information concerning the preparation of aggregates, including the grading of the aggregate when it differs from that given in 7.2.

11.1.6 Any significant features revealed by examination of the specimens during and after test.

11.1.7 Amount of mixing water expressed as mass percent to cement, and

11.1.8 Type, source, proportions and chemical analyses, including Na_2O and K_2O, of any supplementary cementing materials employed in the tests.

11.1.9 A graph of the length change data from the time of the zero reading to the end of the 16 day period.

12. Interpretation of Results:

12.1 When the mean expansion of the test specimens exceeds 0.20% at 16 days from casting (14 days from zero reading), it is indicative of potentially deleterious expansion. This value has been determined from tests of aggregates with known field performance. It is strongly recommended that supplementary information be developed to confirm that the expansion is actually due to alkali reactivity (see Appendix B of CAN3-A23.1).

12.2 When the mean expansion of the test specimens is less than 0.10% at 16 days after casting, it is indicative of innocuous behaviour[5].

12.3 Where the mean expansion of the test specimens is above 0.10% and less than 0.20% at 16 days from casting, the results are as yet inconclusive. It is strongly recommended that supplementary information be developed as discussed in CAN3-A23.1, Appendix B.

13. Precision and Bias:

13.1 Precision data will have to be developed.

13.2 *Bias* - Since there is no accepted reference material for determining the bias of this test method, no statement on bias is being made.

References:

1. R.E. Oberholster and G. Davies, "An Accelerated Method for Testing the Potential Alkali Reactivity of Siliceous Aggregates, Cement and Concrete Research, Vol. 16, pp. 181-189, 1986.

2. G. Davies and R.E. Oberholster, "Use of the NBRI Accelerated Test to Evaluate the Effectiveness of Mineral Admixtures in Preventing the Alkali-Silica Reaction", Cement and Concrete Research, Vol. 17, pp. 97-107, 1987.

3. G. Davies and R.E. Oberholster, "An Interlaboratory Test Programme on the NBRI Accelerated Test to Determine the Alkali-Reactivity of Aggregates", National Building Research Institute, CSIRO, Special Report BOU 92-1987, Pretoria, RSA, 16 pp., 1987.

4. C. Rogers, Ontario Ministry of Transportation and Communications, Personal Communication, Tabulation of mean w/c for acceptable flow of mortar bars with fine and crushed-coarse aggregates, Oct. 25, 1988.

5. R.D. Hooton and C.A. Rogers, "Evaluation of Rapid Test methods for Detecting Alkali-reactive Aggregates", Proceedings, 8th International Conference on Alkali-Aggregate Reaction, pp. 439-434, 1989.